VOLUME 85 NO. HW3
SEPTEMBER 1959
PART 1

JOURNAL of the

Highway Division

PROCEEDINGS OF THE

AMERICAN SOCIETY
OF CIVIL ENGINEERS

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This Journal is published quarterly by the American Society of Civil Engineers. Publication office is at 2500 South State Street, Ann Arbor, Michigan. Editorial and General Offices are at 33 West 39 Street, New York 18, New York. $4.00 of a member's dues are applied as a subscription to this Journal. Second-class postage paid at Ann Arbor, Michigan.

Subject and author indexes, with abstracts, are published at the end of each year for the Proceedings of ASCE. The index for 1958 was published as Proc. Paper 1891; indexes for previous years are also available.

Journal of the

HIGHWAY DIVISION

Proceedings of the American Society of Civil Engineers

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Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

A PLAN FOR A COUNTY MOTOR VEHICLE TRANSPORTATION SYSTEM

Victor W. Sauer,[1] M. ASCE

INTRODUCTION

A plan for a County Motor Vehicle Transportation System should be developed without regard to political boundary lines; it should be financed upon the basis of benefit; and the planned system should be built upon priority of needs. These are the steps necessary to achieve a balanced and integrated system of state highways, county roads, and city streets to best serve the highway user and to encourage optimum social and economic development of the county.

We regard a plan for a County Motor Vehicle Transportation System as a dream set forth in a report or projected upon the drawing board. A system is a dream come true. From dream to plan to system requires cooperation, coordination and communication among all groups who must accept the plan and approve its transformation into a system by the appropriation of necessary funds.

In California today there are many road plans now completed through the combined efforts of the state, the counties, and the cities. Many are now aware that past frictions among different groups interested and concerned in different motor vehicle transportation systems stemmed, many times, from prides and prejudices, but more frequently from lack of funds. There has been a tremendous change toward real cooperative effort. This somewhat recent metamorphosis is due in part to the recognition that the democratic concept of "the greatest good for the greatest number" has a logical application to road matters. Applying this concept to transportation systems, the table on the next page ranks several systems within Contra Costa County in the order of their importance. However, these systems are inter-related and it is essential that the planning for them be done cooperatively in order for each to attain maximum utility.

Note: Discussion open until February 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2144 is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. HW 3, September, 1959.

1. Public Works Director, Contra Costa County, Martinez, Calif.

PRIORITY	SYSTEM
1	Interstate System
2	California Freeway System
3	Contra Costa County Freeway-Expressway-Arterial System
4	Contra Costa County Feeder Road System
5	Contra Costa County Residential Road System

The foregoing comments imply the necessity for having a solid basis for road planning. The basis in Contra Costa County rests upon four major premises:

A. Traffic is no respector of political boundary lines.

B. There should be general financing for general needs and local financing for local needs.

C. Construction should proceed on priorities based upon need.

D. Motor vehicle transportation systems yield important economic benefits other than time and distance savings.

Geography and History Affecting the Plan

Before presenting the Contra Costa County plan, it is desirable to describe Contra Costa County itself and to review the events which preceded the development of the plan. This will permit the plan to be viewed in its physical and historical setting for a better total understanding of its meaning.

Geography

The County is bounded by Alameda County, San Francisco Bay and San Pablo Bay on the west; by Suisun Bay, the Carquinez Straits, and the San Joaquin River on the north; by San Joaquin County delta land on the east; and again by Alameda County on the south. The western half of the County is hilly, dominated by Mt. Diablo. The western ranges, composed of the Berkeley Hills, the San Pablo Ridge, and the Pinole Ridge, run north to south separating the City of Richmond and the Alameda County area from the central and eastern Contra Costa County cities. These hills pose problems since they are a barrier to traffic flow between these densely populated areas. The basin between the Berkeley Hills and Mt. Diablo comprises the Walnut Creek watershed, with certain severe drainage and slide problems occurring in the winter months.

"The County is remarkable for extreme soil variations with sudden changes and a great many different formations.* The close juxtaposition of good sandy soils and very active fine clays is baffling and treacherous. A large part of the basic formation consists of sandstone ridges running

*I am indebted to Mr. Victor A. Endersby, our former Materials and Testing Engineer, for permission to quote this and the following two paragraphs from a paper he presented at the 1954 annual meeting of the Institute of Transportation and Traffic Engineering of the University of California.

from southeast to northwest, folded in complicated ways and often upended. The sand tends to be quite fine, and the cementing material is a very fine active clay. In the eastern part of the County is a considerable dune formation and plains of wind-deposited sandy soil.

"The matter of drainage furnished a whole series of puzzles. It is difficult to know where a spring or underground stream exists unless it is close enough to the surface to feed vegetation or has produced a slide. Water may be struck almost anywhere during heavy construction; and a large number of springs and water seams are bone dry during the late summer so that in winter a spring may show up where it would not be suspected during dry season construction.

"Meterologically, the County's climate is a front between the Pacific Ocean climate and the Sacramento-San Joaquin Valley climate. This combination of uncertainties results in considerable climatic variation from year to year and the County is full of micro-climates, both as to temperature and rainfall. Rainfall, for example, will double in some areas within five miles."

History

Historically, the first county industrial and trade centers followed the water route on the north, forming the major cities along the shore line: Richmond, Martinez, Pittsburg, and Antioch. The first railroads paralleled this route as well as did the first highways. The interior of the county was rural, with grain its chief commodity. Transportation from farm to port was by wagon over roads radiating from the interior to the coast line; little access was provided directly from the San Francisco-Oakland Bay Area over the hills to the central portion of the county. This resulted in a slow growth of the presently heavily populated area of Lafayette-Walnut Creek-Concord-Danville, in the central part of the county. This area's potential for homesites and for recreation was recognized early, however, and was opened for these uses by the construction of the Broadway low-level tunnel through the hills to Oakland and Berkeley, in 1938. The overflow of population from the heavily populated Bay Area literally flooded through this portal after World War II. The area is still growing with new residential subdivisions mushrooming throughout. The new population consists heavily of commuters whose traffic chokes the highways during peak hours and, to support the increased population, trucking has been steadily increasing.

Fortunately, the impact of these changes affecting roads fell upon a local government already partially equipped to meet it. To illustrate this and to provide the historical setting for the Contra Costa County Motor Vehicle Transportation plan, here are the background events leading to the plan.

1. The First Contra Costa County Road Bond Issue

In July, 1919, the county passed a $2,600,000 road bond issue for the improvement of 100 miles of county roads. Today we can still ride over a considerable mileage of these roads. Much of the remainder has disappeared by incorporation into subsequent improvements. This 1919 bond issue stimulated an interest in roads that remains today.

2. The Collier-Burns Act of 1947

The wisdom of the California State Legislature in passing the Collier-Burns Act of 1947 becomes increasingly obvious with the passage of time. One

important feature of this Act provided for proper county road administration: "Policies will be determined by the Board of Supervisors and carried out by the Road Commissioner." The Act also benefited the California Division of Highways. The consequent achievements of the Division have rightly drawn state and national attention, and because of the relative magnitude of the Divisions' activity, the tremendous importance of the Collier-Burns Act to California counties in road administration and financing is sometimes obscured.

3. The Contra Costa County Road Bond Issue of 1952

By the early 1950's the cooperation, coordination, and communication among the various groups interested in better roads again resulted in a county road bond issue, this time for $10,250,000. This 1952 bond issue was predicated upon the removal of the then urgent, non-deferrable deficiencies measured in terms of structural, capacity, and safety ratings. Approximately 78 miles of county roads, a railroad underpass, and some bridges were approved for construction. About eight and one-half miles of new roads were included where the traffic benefit and service potential were obvious, but in general there was no plan for future trafficways with detailed right-of-way requirements.

The taxpayers were promised better roads and reduced taxes if the bond issue was approved and these promises have been kept. The bond issue is being paid off with cheaper money than was borrowed, a progressively broadened tax base is being developed, and there is the immediate benefit of huge savings for the highway user. For example, the time and distance savings for our Cummings Skyway were $909,000 in one year while the total cost of this bond issue project was only $1,434,210.

The taxpayers also have found it a matter of interest and satisfaction that since 1953, for normal years without floods, there has been a large reduction in cost per mile for road maintenance resulting in an average saving of more than $400,000 a year. A part of the savings is due to a reduction in the road maintenance force by sixty-seven men. Another savings resulted from the disposal of equipment having a book value of $165,000. These savings were made despite the fact that there are 104 miles more of road to maintain in 1958 than there were in 1953.

This 1952 bond issue clearly demonstrated the direct and immediate cash benefit of good cooperation, coordination and communication among the technical staffs, taxpayers, and official groups in our county. The term "technical staffs" used here and elsewhere includes engineers, planners, and traffic specialists, all of whom must work together as a team.

4. The Local Road and Street Deficiency Reports

Local road and street deficiency reports have been required every two years since 1952 for the California Joint Interim Committee on Transportation Problems. The preparation of these reports provided sufficient stimulation to pull together more strongly than before city and county technical staffs. An extra dividend of this mutual effort was the creation of the City-County Engineering Advisory Committee which is described later.

A review of the deficiency reports prepared over the past six years is in the table on facing page. The standards used for all reports have been essentially the same. The increase from 1956 to 1958 is primarily due to increases in traffic and to consideration of all deficiences in 1958 where previously only "critical" deficiencies were listed.

1952	1954	1956	1958
$37,000,000.	$35,000,000.	$34,000,000.	$37,000,000.

5. The United States Bureau of Public Roads "210" Report

Section 210 of the Federal Highway Act of 1956 required each state to provide an estimate of the cost to remove the existing and future deficiencies on state highways, county roads, and city streets for the 15-year period from 1956 to 1971. Every city and county in the state voluntarily made and submitted its own report to the California Division of Highways — a significant indication of the realization of the importance of road planning to local government. The work on the "210" report improved participation at policy making, technical, and administrative levels and strengthened the concept that "Traffic is no respector of political boundary lines."

6. The Senate Concurrent Resolution No. 26 of the 1957 State Legislature

This resolution required a study that resulted in the proposed California Freeway System and provided as well a sound basis and a prerequisite for all future cooperative motor vehicle transportation planning. For these reasons it is imperative that the California Freeway System be adopted and built on schedule. (See page 22 for a copy of Senate Concurrent Resolution No. 26).

Contract provisions of Senate Concurrent Resolution No. 26 permitted and helped finance local city-county-state cooperative thoroughfare or trafficway studies. Either a city or county could be the contracting agency; and dual contracts were necessary; one with the consultant and one with the state. (See pages 18 and 21 for copies of agreements between Contra Costa County and the consultant and between Contra Costa County and the State of California). From the city-county-state cooperative road studies the state received the data needed and required by the resolution, and the cities and counties obtained the shape and location of tomorrow's local trafficways.

7. The Joint Interim Committee on Highway Problems Created by Senate Concurrent Resolution No. 134 of the 1957 State Legislature

This legislative committee held statewide hearings on the proposed California Freeway System. The committee has finished its hearings and at the time of preparation of this paper was scheduled to report its recommendations to the State Legislature.

We think it of great significance that eleven times Senate Concurrent Resolution No. 134 specifically indicates that city streets and county roads are of interest and concern to the State Legislature. The Legislature has increased again the interest in local motor vehicle transportation planning. (See page 24 for a copy of Senate Concurrent Resolution No. 134).

8. The County Setback Ordinance

In the application of this ordinance to protect today the rights of way for roads of tomorrow, we have found it desirable to explain our proposals. Conferences with representatives of cities, industries, Chambers of Commerce, and civic leaders in different areas have resulted in agreement to date. The only question we have been unable to answer is: "How soon can you improve this road?" This setback program is, in effect, creating area demands for better roads. The sum of all area demands would be equal to an entire future county demand.

9. The Rotating Right-of-Way Fund

A newspaper reporter suggested that the county develop a rotating right-of-way fund similar to the California Division of Highways' fund which has been so successful. The idea was given wide publicity and received widespread favorable comment and support.

Contra Costa County sponsored legislation, passed by the State Legislature, permitting counties to establish such funds. The prospects are good for the near future creation of this fund which has a limitation of one-half of one per cent of the county's assessed valuation.

10. The Mayors' Conference

The Mayors' Conference, formed in June, 1951, is composed of the mayors of our eleven cities. It has been instrumental in developing unity among city governments and in improving city-county relationships. If, and only if, there is cooperation among the policy and law-making bodies of the county, can cooperation among the technical staffs be, in the first place, possible, and in the second place, effective.

11. The City-County Engineering Advisory Committee of Contra Costa County

Initiated by the Mayors' Conference, this committee, mentioned earlier, was endorsed by the Mayor's Conference, the Board of Supervisors, and by each individual city. The broad purpose of the committee is "to promote mutual interest and coordination of effort in city and county public works matters and to make appropriate recommendations to our respective City Councils and to our Board of Supervisors." The official recognition given the cities' and the county's engineering staffs hastened the development of the philosophy of a City-County Thoroughfare System commented upon in the next paragraph.

12. The Adoption of the Philosophy of a City-County Thoroughfare System by the Cities and the County

The Mayors' Conference and the Board of Supervisors directed the City-County Engineering Advisory Committee to develop a plan for the improvement of city streets and county highways. The idea for a City-County Thoroughfare System resulted and was approved by all the policy-making bodies concerned.

It is to be emphasized that this idea for a City-County Thoroughfare System was a fundamental concept and was not an engineering plan for precise or future projected routes, or finalized rights of way and geometric requirements. THIS WAS OUR DREAM!

13. The City-County-State Cooperative Road Study

Under the provisions of Senate Concurrent Resolution No. 26, the county, with the approval and support of the cities entered into contracts for a road study which is now complete and is being very carefully reviewed. THIS IS OUR PLAN!

Carried out by an engineering consultant, this study has made a reality of our City-County Thoroughfare concept adopted by the Mayors' Conference and the Board of Supervisors and the individual cities. The City-County Thoroughfare System will be a selected portion of the system of freeways, expressways, and arterials developed in the cooperative Senate Concurrent Resolution No. 26 study. THIS WILL BE OUR SYSTEM! The foregoing background of events demonstrates the growth toward a high measure of solidarity and unity

of purpose in road matters in Contra Costa County. In the following comments on the study and the resultant plan, certain features that may be of interest are outlined.

The Contra Costa County Plan for a Motor Vehicle Transportation System

Purpose and Scope

The county's plan for a network of trafficways to serve the entire future traffic needs of the county has a primary target year of 1980 for design purposes. Supplementary design data was developed for the secondary target year, 1963, to show which elements of the 1980 system had the highest priority and should be constructed first.

However, the rights-of-way requirements were developed for ultimate population conditions of the county. "Ultimate" is defined as the time at which the optimum development of all individual areas of Contra Costa County occurs. The years 1963 and 1980, then represent estimated percentages of population of the "ultimate year." Either 1980 or the "ultimate year" can arrive in 1970, or 2000, or some other year, depending upon the rate of population growth. However, with ultimate rights-of-way requirements obtained or protected, there is no problem.

The core of the plan is this: It gives the shape and location of tomorrow's roads - the freeways, expressways, arterials, and important feeders that will comprise Contra Costa County's future motor vehicle transportation system. The recommendations for new or expanded existing facilities are presented on general maps and strip maps, with major urban areas depicted on individual maps. A map on page 12 shows these freeways, expressways and arterials for the target year 1980. Routes designated by circles on this map are those ultimately required as freeways, expressways or arterials after 1980. Routes for proposed freeways and expressways had sufficient detailed study to insure that the facilities could be built to required standards along the general, but not precise, alignment indicated on the plan. The importance of the feeder system of the plan was recognized by the consultant who made a distinction between feeders of general county interest and those of local area interest.

Time Element and Costs

It has taken nineteen months to complete the study, at a cost of $160,000, exclusive of the cost for right of way estimating and detailed topography, both of which were supplied by Contra Costa County for reasons given later in these comments. The cost of $160,000 was equally borne by the cities, the county, and the state.

Administration and Non-Technical Highlights

The county agreed to provide all necessary aerial photographs, survey information, and estimates of rights-of-way costs. Because the necessary amount of photography and surveying was an intangible, it was difficult to include such items in an equitable contract. The Right of Way Division of the Public Works Department was in an excellent position to supply the necessary right-of-way information by virtue of its thorough and intimate knowledge of county land values.

The Public Works Department was named in the contract as coordinator for the study. The Public Works Director appointed a coordinating committee consisting of his Deputy, as Chairman, the Traffic Engineer and a member of the Advance Planning Section of the Planning Department. This committee held many regular and special meetings with the consultant's staff and reviewed his monthly written progress reports, which were required by the contract.

Meetings of the City-County Engineering Advisory Committee were devoted to discussions and explanations of different phases of the study by the staff of the consultant.

The Public Works Department organized, and was the headquarters for the campaign to keep the general public informed of the study and to secure needed data from highway users. The highway users cooperated well and contributed vitally to the report by completing and returning more than 37,000 of the 146,000 postal card questionnaires mailed on the internal origin - destination survey part of the study. The press, radio, television, and billboard industries, plus labor organizations, the Chambers of Commerce, the Development Association, the Industrial Association, and other groups joined in informing the public of the desirability and necessity for returning the questionnaires. Feature stories, editorials, spot announcements, window posters, leaflets, and huge billboards were used to bring the message to the public.

Methods and Conduct

All pertinent available data were collected and analyzed. These data included road inventories, origin and destination studies, twenty-six previous significant reports, traffic volume counts, population records and projects, and many other related studies and sources of information.

A great deal of information on traffic volume data was made available by the state, the county, and the cities. Over one thousand individual traffic counts made in 1956, 1957, and 1958, were reviewed, and counts going back as far as 1946 were checked to determine growth trends.

The collection of new data involved four phases of study to bring existing information up-to-date and to provide the required additional data to permit detailed analysis of Contra Costa's trafficway needs for now and the future. These are:

1. Traffic Volume Counts
2. Origin and Destination Surveys

Since labor costs generally have risen very sharply since the end of World War II, the most desirable type of origin and destination study, namely the home interview, has become unfeasible. For this reason, the study turned to postal cards for the internal survey.

The Highway Planning Survey Department of the California Division of Highways some time ago adopted a grid system for the entire state. In addition to coding the information from the internal survey by zones, it was decided, upon the recommendation of our consultant, to assign to each trip terminal a pair of coordinates relating it to the planning survey grid. Although the planning survey usually is based on one mile or a one-tenth mile intervals, for the purpose of our study a two-tenths mile grid was found desirable and used.

Although this is a much more difficult, time-consuming, and expensive way of coding trips, a number of advantages were gained. For one, information on the trip terminals is now available within a two-tenth square mile area and in any future re-run of the data, the study would not necessarily be tied to zone boundaries. This is especially important in areas of rapid growth where the present zones may not correspond with the need of future studies, since with this device the zone boundaries can be changed to fit the conditions. Secondly, through the use of this grid, studies in adjacent counties can easily be correlated. Eventually the entire state could be tied together.

The usual "desire line" method of showing the results of an internal origin and destination study results in such a mass of lines that, unless they are severely culled for the low-intensity desires, this sheet becomes almost unintelligible. For this reason, it was decided to show the results as traffic contours, a technique developed by the California Division of Highways. The contours indicate the intensity of trip desires at any one point. This method has one drawback in that it shows only the traffic concentration at any one point, but not where this traffic comes from or wishes to go. To overcome this difficulty, supplementary contours on a one-mile grid were prepared for the entire county on a directional basis which made it possible to identify desires in, for instance, northwesterly or northeasterly directions. This then shows not only traffic concentration but also direction.

3. Population Potential and Projected Land Use

For any given area of the county a change in population or land use will change the need for facilities and provisions for the movement of goods and people. In projecting highway needs it is essential that there be an integrity in zoning and that projections can be made of predictable factors which affect vehicular travel requirements. The most important of these factors are:

a. The number of people who can reasonably be expected to live in Contra Costa County under the optimum condition of development for a balanced land use plan.

b. The stage of development that can be realized by 1980 and 1963, the primary and secondary target years. The table below shows the projected population in number and per cent of growth for key years.

YEAR	POPULATION	% OPTIMUM GROWTH
Ultimate	1,297,000	100
1980	842,000	65
1963	477,000	37
1958	375,000	29

c. The distribution of population by areas within the county.

d. The location of commercial and industrial centers of traffic attraction for the target years 1963 and 1980.

Maps showing "Projected Population Distribution within Contra Costa County" and "Projected Land Use, Projected to 1980," follow.

PROJECTED POPULATION DISTRIBUTION
WITHIN CONTRA COSTA COUNTY
O & D ZONES IDENTIFIED BY NUMBERS
COUNTY POPULATION ESTIMATE
YEAR POPULATION
1958 319,000
1963 477,000
1980 842,000
ULTIMATE 1,297,000
ULTIMATE
1980
1963
1958
40,000
30,000
20,000
10,000
0
RICHMOND
SAN PABLO
PINOLE
HERCULES
CROCKETT
PORT COSTA
MARTINEZ
PACHECO
CONCORD
PLEASANT HILL
WALNUT CREEK
DANVILLE
ALAMO
MORAGA
LAFAYETTE
ORINDA
SAN RAMON
BYRON
BRENTWOOD
OAKLEY
ANTIOCH
PITTSBURG
CLAYTON
MARTINEZ
CONCORD
DANVILLE
SAN RAMON
Tudor Engineering Company

CONTRA COSTA COUNTY, CALIFORNIA
STUDY MAP SHOWING
PROJECTED LAND USE
JANUARY 1957

SAN JOAQUIN COUNTY
ALAMEDA COUNTY
SYSTEM OF FREEWAYS, EXPRESSWAYS & MAJOR STREETS
RECOMMENDED FOR CONTRA COSTA COUNTY
SCALE IN MILES

4. Road and Street Inventory and Sufficiency Ratings

Three hundred eighty miles of city streets, county roads, and state highways were carefully inspected and the results compiled to permit a subsequent evaluation of the existing system on a sufficiency basis. "Sufficiency" in this sense consists of three parts of about equal importance:

a. Structural conditions

b. Safety, including sight distance, consistency of construction to uniform standards throughout length of roadway under consideration, and adequacy of width

c. Service, which reflects the efficiency of the route in serving traffic and is measured by the elements which tend to inconvenience the motorist.

A sufficiency rating system which could be of continuing value to the county was developed. The scoring system was derived from the most applicable portions of several accepted rating systems. Specific ratings were established for local streets, major streets, two-lane rural roads and multi-lane highways. Numerical values were assigned these ratings for present and future use.

The Future of the Plan

Contra Costa County Highway Advisory Committee Recommendations

Contra Costa County will look to its County Highway Advisory Committee for recommendations on the plan. This committee of thirty-one members includes broad representation from local government, (eleven mayors and two supervisors) and leaders from labor, business, industrial, agricultural and civic groups. It:

1. Develops a better understanding of our highway problems within the entire county.

2. Makes reports and recommendations to the State Highway Commission or Joint Interim Committees on State Highway matters.

3. Works as a unit toward common city and county goals rather than from individual viewpoints.

The Highway Advisory Committee is reviewing the plan to foster agreement on the details of a freeway-expressway-arterial system, which includes the City-County Thoroughfare plan.

After committee approval, each city, the Mayors' Conference, and the Board of Supervisors must adopt the plan.

A listing of construction priorities for action by 1963, as recommended by the consultant will also be reviewed by the Highway Advisory Committee, and the Committee's recommendations also will be presented to each city, the Mayors' Conference, and the Board of Supervisors for adoption.

Financing Suggestions

The freeway-expressway-arterial system, including contingencies, administration and rights of way is estimated to cost $250,000,000. The additional cost of the county feeder and residential systems raises the total to

$509,000,000. A financing program must be determined and additional revenues obtained since present funds are insufficient to handle Contra Costa County's existing and future road needs. See Table I, "County Funds - Sources and Possible Distribution," for a suggestion on equities in financing, and Table II, "Preliminary Financial Study," giving an overall view of the road deficiency problem in Contra Costa County and making several financial suggestions for additional revenues to remove the deficiencies.

Additional Economic Values of Roads

It is obvious that substantial increases in funds are needed to liquidate the deficiencies on Contra Costa County's roads and to place the plan in effect. For roads to get a fair and necessary share of available monies it is essential that what may be new perspectives on the value of roads be emphasized. In addition to time and distance savings there are other benefits obtained from roads. Two of these benefits are the broad general economic and the service-way concept.

1. The Broad Economic Benefit

Robinson Newcomb, a Consulting Economist in Washington, D. C., and formerly a member of the President's Council of Economic Advisors, has this to say on the general economic benefit in the June 19, 1958, issue of the "Engineering News Record":

> "Despite the substantial increase in highway expenditures heralded by the Federal Highway Act of 1956, new road facilities will not be provided fast enough to meet the needs of our growing economy unless both the size and the tempo of the program are stepped up further. This will be necessary because, if the economy is to continue to grow at the historically desirable rate of at least 3% a year, highway transportation and, therefore, new road facilities must grow at an even faster rate.
>
> "This challenging fact, as well as some suggested figures on the needed amount and rate of highway construction, emerge from a study the author has recently made, comparing the growth pattern of highway facilities with that of traffic and of general economic growth as measured by the gross national product. (GNP).
>
> "Among the conclusions to be drawn are the following:
>
> > Adequate highways increase the gross national product by making it possible to move a greater volume of goods economically.
>
> "Transportation has always supported and promoted business growth, and highway transportation, since the post World War I period, has been particularly effective in this respect.
>
> "Because of the specialization that has occurred in business and production, highways have become a part of their assembly lines. Today, goods travel miles between processing steps where formerly they only traveled feet. The result is that more vehicle miles are required per unit of business done with the consequence that highway facilities must be increased at a faster rate than business itself increases. But this fact has not always been recognized. All of us know that the economy cannot grow without electricity or water, or steel. We recognize the need for continuing expansion in the capacity for supplying such essentials. We are glad to see money borrowed and stocks and bonds sold for this purpose.

TABLE I

COUNTY FUNDS - SOURCES AND POSSIBLE DISTRIBUTION

EXISTING SOURCE	DISTRIBUTION		
	GENERAL NEED		LOCAL NEED
	Freeway Expressway Arterial System	County Feeder Road System	County Residential Road System
FROM STATE			
Highway Users Revenues	X	X	
"In Lieu" Funds	X	X	
FROM FEDERAL GOVERNMENT			
Federal Aid Secondary Funds (Including State Matching Funds)	X	X	
LOCAL SOURCES			
Property Burden			
County-wide			
General County Property Tax	X	X	
Bond Issue (Gen'l Prop.Tax to retire)	X	X	
Unincorporated Areas			
Assessment Districts			X
Supervisor Road Dists.			X
Sales Price New Homes		X	X
Permanent Road Divisions			X
Out-of-Pocket			
Sales Tax*	X	X	X
Fines	X	X	
Private Financing			X

*Sales tax monies now deposited in County General Fund. If sales tax revenue should be used for road purposes, then property tax rates in Preliminary Financial Study would be reduced correspondingly.

"We also know that the economy cannot grow without adequate traffic facilities. But we have not faced up as straight-forwardly to the fact that, if the economy is to grow, highway capacity must grow, and this growth must be financed.

"It is easy to illustrate how inadequate facilities limit transportation capacities and, therefore, the volume of goods that can be moved comfortably. The high cost of traffic delays, traffic jams, and traffic accidents is well known. The deterrent effect of such costs on the growth of the economy is not as well recognized. We know that adequate highway facilities encourage business and residential construction just as we know that they encourage more traffic."

PRELIMINARY FINANCIAL STUDY

TABLE II

$509,000,000*	DEFICIENCIES	REVENUE SOURCES	REVENUE AMOUNTS	NOTES:
COUNTY RESIDENTIAL ROAD SYSTEM $360,000,000*	Maintenance 26 Million	17¢ Prop.Tax Unincorp. Area	26 Million	1. Study covers period 1958 to 1980.
	Construction 123 Million	Property Burden Unincorporated Areas Assess.Dists. or Other	67 Million	2. Tax figures based on projected averages. 3. Study used present City Limits. 4. Study used present prices.
		Subdivision Development - Sale Price of Homes	56 Million	5. Cost estimates for construction include right of way, contingencies and administration.
COUNTY FEEDER ROAD SYSTEM $273,000,000*	Maintenance 14 Million	Subdivision Development - Sale Price of Homes	43 Million	
	Construction 73 Million	No Existing Revenue - 44 Million Deficit	-93 Million Deficit	
CITY AND COUNTY FREEWAY, EXPRESSWAY AND ARTERIAL SYSTEM	Maintenance 23 Million	No Existing Revenue - 49 Million Deficit		
		Federal Aid	12 Million	
		Traffic Fines	12 Million	
	Construction 250 Million	Highway Users Allocations to County	118 Million	
		In State's Proposed Freeway System ---- Present City-County Jurisdiction	82 Million	

County General Tax and/or Gasoline Tax to raise 93 Million

SELF HELP

PLAN A
GEN'L COUNTY TAX OF 37¢ -$93,000,000

PLAN B
GEN'L COUNTY TAX OF 27¢ -$68,000,000
BOND ISSUE PROP.TAX 12¢-$25,000,000
$93,000,000

SELF HELP & STATE AID

PLAN C
GAS TAX 5/8¢-$54,000,000
GEN'L COUNTY TAX OF 15¢ -$39,000,000
$93,000,000

PLAN D
GAS TAX 5/8¢-$54,000,000
BOND ISSUE PROP.TAX 12¢-$25,000,000
GEN'L COUNTY TAX OF 5¢ -$14,000,000
$93,000,000

STATE AID ONLY

PLAN E
GAS TAX 1.1¢=$93,000,000

*Cumulative Deficiency Total

2. The Serviceway Concept

County roads as well as city streets are serviceways provided for the public in general. These serviceways provide the means of transportation of vehicles, pedestrians, and utility services, such as electricity, telephone, water, gas, sewers and refuse disposal. Roads, then, handle more traffic than just goods and people, who legally can be on foot, horseback, or even piggy-back. The same citizen who prefers motor vehicles to the latter three forms of transportation also wants better services in life, such as electric lights, dishwashers, garbage disposal units, telephones, hot and cold running water, inside toilets connected to sewers, and garbage service.

These low cost, high quality services are excellent, and where they properly use the road rights of way, they should continue to be permitted to do so. There is no implication that the home owners' county road budget should equal the home owners' service budget. However, it seems fair to emphasize that in terms of relative needs of the jobs which have been done, and remain to be done, in terms of services and roads, the road program has not had an equitable and necessary share of funds.

This thought is illustrated by the table on the next page, showing the relative costs of taxes, utility services and roads for the owner of an average Central Contra Costa County home, with an assessed valuation of $4,000.

Fiscal Year 1958 - 1959

	Cost	Tax Rate	Cost Per Month
All School District Taxes	$199.92	$4.998	$16.66
Special District Taxes	86.52	2.163	7.21
County General Taxes	91.60	2.290	7.63
Total Taxes	$378.04	$9.451	$31.50
Average Total Bill for Services (Utilities)	$351.00	$8.775*	$29.25
Home Owners Gross Road Budget **	$ 33.57	$0.839*	$ 2.80
Less Share of Fines, Gas Tax, In Lieu	-18.72	0.468*	-1.56
Home Owners Net Road Budget	$ 14.85***	$0.371*	$ 1.24

* Tax rate equivalent
** Contra Costa County's 1958-59 Road Budget is $6,222,047
*** From County General Fund

CONCLUSION

Today, Contra Costa County has an excellent report setting out a plan for an integrated and balanced network of state highways, county roads, and city streets. To communicate this plan countywide may take several months. We

are optimistic that this communication will be successful because we think that past communication efforts have set the stage for general acceptance of road programs reasonably in line with the desires of the public.

However, the mere acceptance of the plan does not necessarily mean immediate action. The huge cost of the plan must be met. Several alternate means of financing have been suggested and there are other means which must be considered.

We believe that the county's citizens, who have traditionally supported a strong road program, will continue to provide essential backing for the development of an improved motor vehicle transportation system. This strong support, we feel, will not be weakened by the knowledge that they can get their ultimate road needs met at no greater additional cost than they now pay to have their garbage removed.

Agreement for City - County - State Cooperative Road Study Between Contra Costa County and Tudor Engineering Company

THIS AGREEMENT, made and entered into this 23rd day of July, 1957, by and between the COUNTY OF CONTRA COSTA, hereinafter referred to as the County, and TUDOR ENGINEERING COMPANY, hereinafter referred to as the Engineer.

WHEREAS, the County is desirous of having a study made which will be an over-all countywide plan of freeways and expressways, such study to include State, County and City elements, and to locate the potential freeway and expressway routes of such a Countywide system and the necessary connections thereto as nearly as is practicable in advance of detailed engineering design of the projects.

NOW, THEREFORE, it is hereby agreed as follows, to wit:

1. The County hereby employs the Engineer and the Engineer agrees to and accepts such employment to perform the following services upon the following terms and conditions and in consideration of the following payments.
2. The Engineer shall proceed without delay to perform the following work:

A. Collect all available data pertinent to the study, including:

1. Inventory of State and County highways and principal city streets that are feeders to the highway system,
2. Traffic volume counts made within and adjacent to the County boundary,
3. Traffic origin and destination counts
4. Accident records,
5. Population of the County and communities, past and present
6. Automobile registration of the County, past and present
7. Industrial growth of the County,
8. Planning studies and zoning for land use within the County,
9. Planning studies for future highway and principal street developments within the County,
10. Current construction cost records in the area,
11. State and County highway design standards.

B. Collect essential new information and data including:

1. Limited additional volume counts of traffic, as needed,
2. Make an inventory of highways, roads and streets, as needed, including both physical characteristics and traffic characteristics. Provide, through speed and delay studies and capacity calculations, a measure of the ability of the existing roadway network to handle traffic loads and show areas of excesses and deficiencies,
3. Make a comprehensive over-all origin and destination study showing present and future traffic patterns of traffic between internal zones, internal zones to external areas, external areas to internal zones and through traffic. The origin and destination study to be checked by a screen line so that accuracy will meet standards set by the Bureau of Public Roads,
4. Make land use studies and plans for areas of the County not already so covered. Review existing plans for possible changes in land uses. Make study of employment potential, location and size of labor force, et cetera.

C. Analyze the data collected under A and B above, including:

1. Estimate of future population growth by areas within the County,
2. Analyze the present traffic flow within the County using origin and destination and volume data to estimate the following:

   a. Average daily traffic for autos, trucks and other vehicles
   b. Prepare zone to zone traffic movement tables
   c. Prepare desire line maps,

3. Estimate the traffic flow within the County for 5 years and 20 years hence. Use the data for the present flow adjusted to reflect the future population growth by County areas, vehicular use per resident, et cetera,

   a. Average daily traffic for autos, trucks and other vehicles
   b. Prepare zone to zone traffic movement tables
   c. Prepare desire line maps,

4. Estimate the traffic flow within the County when a state of saturation of the population, according to land use plans, has been reached. This is to establish right of way needs and will not be carried to the same detail as 2 and 3 above.

D. Prepare a basic highway plan of the County to include all freeways, expressways and important feeders thereto including State, County and City elements. Test roadway network as determined on basis of future traffic desires by assigning traffic on both time and distance saving bases. Evaluate impact of new highway facilities on intensity of land use in adjacent areas. Modify roadway network layout as needed and check again. Use sufficient cycles of successive approximations to obtain satisfactory final plan.

1. This will include, based on traffic volumes 5 and 20 years hence the following:

   a. Location of elements based on

      1) Aerial photographs and topographic surveys to be provided by the County,

2) Present pattern of highways, roads and streets,
3) Traffic desires as determined in C-3, above,

b. Capacity of units
c. Interconnections
d. General plans including widths of roadways, right of way requirements, roadway cross-sections, principal drainage and other essential elements.

2. Prepare an estimate of right of way needs for traffic volumes for conditions of ultimate population saturation.
3. Develop design standards for various components of final trafficways plan.

E. Prepare general cost estimates of the County highway plan for 5 and 20 years hence to be divided by principal structures and logical sections of highway, with items such as right of way, construction, engineering and contingencies shown separately. Costs will be based on present cost levels. The County will provide all right of way estimates.

F. Prepare a table of improvements, with priorities for those projects recommended to be constructed within 10 years.

G. Prepare and print a report including:

1. Description of methods of study,
2. Results of traffic counts including table and maps,
3. Strip maps of principal highway improvements recommended,
4. Layouts of all principal interconnections,
5. General maps and standards of all other improvements recommended.
6. Methods of making cost estimates,
7. Tabulation of all cost estimates by individual improvements,
8. Tabulation of recommended priority groups,
9. Report will be on bond paper, or equal, with maps and figures in appropriate colors, clear type and suitably bound; 300 copies will be provided with additional copies available at cost.

3. The County agrees to provide all necessary aerial photographs, survey information and estimates of right of way costs. It further agrees that all agencies of the County will cooperate with and assist the Engineer in every reasonable way to the end that the Engineer will obtain all necessary information and data required by him to perform the services herein provided for. The County further agrees that it will make every reasonable effort to obtain similar cooperation and assistance from the State and Cities.

4. For the services set forth in paragraph 2 above the County agrees to pay the Engineer the lump sum of One Hundred Sixty Thousand Dollars ($160,000.00). This amount shall be payable in thirteen (13) installments of Eleven Thousand Dollars ($11,000.00) each, commencing on the tenth day of September , 1957, and the tenth day of each month thereafter, and a final payment of Seventeen Thousand Dollars ($17,000.00) when all work covered by paragraph 2 of this Agreement is completed.

5. It is mutually understood and agreed upon that the Engineer shall complete the work listed in paragraph 2 above within fourteen (14) months of the date of this Agreement.

6. The Engineer shall coordinate his work with the County Department of Public Works and such other County, State and City agencies as the Department shall designate and shall consult with each of these agencies at such times and frequencies as may be necessary and appropriate. The Engineer shall make monthly progress reports of his work in writing.

7. The Engineer is employed herein to render a professional service only and any payments made to him are compensation solely for such services as he may render and recommendations he may make.

This Agreement may be terminated at any time by mutual agreement of the parties hereto.

IN WITNESS WHEREOF, said County of Contra Costa has caused this Agreement to be executed by the Chairman of the Board of Supervisors and the County Clerk and caused its official seal to be hereunto fixed, and Tudor Engineering Company has caused these presents to be executed as of the date hereinabove set forth.

City - County - State Cooperative Road Study
Contract Between the State of California and Contra Costa County

THIS AGREEMENT, is entered into by and between the COUNTY OF CONTRA COSTA, State of California, a political subdivision thereof, hereinafter referred to as "COUNTY," and the STATE OF CALIFORNIA, DEPARTMENT OF PUBLIC WORKS, DIVISION OF HIGHWAYS, hereinafter referred to as "STATE."

WHEREAS, the Legislature of the State of California at its 1957 regular session adopted Senate Concurrent Resolution No. 26 which requested the Department of Public Works to undertake a study to provide a basis for an over-all State-wide plan of freeways and expressways regardless of jurisdiction; and

WHEREAS, Senate Concurrent Resolution No. 26 requests the Department of Public Works to employ by contract or otherwise engineering consultants or other specialists for conducting the study and preparing the necessary reports; and

WHEREAS, cities and counties of the State of California are requested by Senate Concurrent Resolution No. 26 to cooperate with the Department of Public Works in the conduct of the study; and

WHEREAS, it has been found by the Department of Public Works that in some cases the most expeditious and least costly method of conducting this study is to cooperate with the cities and counties in the making of an overall survey of the cities' and counties' needs in planning for future growth and for the city or county to employ the engineering consultants and specialists to perform the services for State and for the city or county; and

WHEREAS, County has entered into an agreement with such engineering consultants and specialists to conduct a study and prepare and report thereof as required by State, a copy of which agreement is attached hereto as Exhibit "A"; and

WHEREAS, State is requested by Senate Concurrent Resolution No. 26 to defray the costs of such studies from money available for highway planning, and that State now desires to enter into an agreement with County to pay for the value of services to be performed for State:

NOW, THEREFORE, it is hereby understood and agreed between the parties hereto as follows:

1. That County will:

A. Deliver to State 10 copies of the report of the consultants which will be delivered to County pursuant to Section 2. G. of Exhibit "A" and which will also contain all that information prepared pursuant to Section 2. D. of Exhibit "A."

B. Deliver to State a report containing the information provided for in Section 2. D. of Exhibit "A" immediately upon receipt thereof by County, which in no event shall County agree to receive after June 30, 1958, without the written consent of State.

C. In the event consultants do not deliver the report to County as required by Section 2. D. of Exhibit "A" by June 30, 1958, County will pay State the cost of completing the studies and preparing the report necessary for the requirements of State.

D. Upon request of State, furnish a copy of progress report which County receives from consultants employed pursuant to Exhibit "A."

E. In no event modify its agreement with the engineering consultants or specialists employed by County pursuant to Exhibit "A" without the written consent of State, if such modification affects the provisions relating to the information to be furnished to State pursuant to this agreement.

II. That State will:

A. Pay to County one-third of the amount to be paid consultants pursuant to Section 4 of Exhibit "A," but in no event shall this exceed the amount of $53,333.34, and to be paid upon receipt by State of a report of the findings and recommendations provided for in Section 2. D. and Section 2. G. of Exhibit "A," or, in the event the agreement is terminated pursuant to the agreement contained in Exhibit "A" pay to County the reasonable value of services performed for State, but in no event shall this amount exceed that which State is required to pay if the agreement had not been terminated.

III. That this agreement constitutes the entire agreement between the parties, hereto for the services to be furnished pursuant to this agreement and that this agreement can be modified, altered or revised with the written consent of both parties hereto.

IN WITNESS WHEREOF, the parties hereto have executed this agreement this _____ day of _____ 1957.

Senate Concurrent Resolution No. 26

WHEREAS, The Legislature of California finds:

a) Adequate, safe, and economical highway transportation is vital to the future development of the State of California.

b) It has been amply demonstrated that properly designed and located freeways and expressways are the most economical means of providing highway adequacy and safety.

c) California is rapidly developing individual freeways and expressways and segments thereof, but in many cases on a piecemeal basis, which program has been greatly accelerated by the enactment of the Federal-Aid Highway

Act of 1956 and will be expanded considerably more if Congress carries out its stated intentions regarding apportionments of federal funds for interstate highways.

d) There is need for the people of California and its agriculture and industry to be informed of plans for the ultimate freeway and expressway system of the entire State as nearly as such can now be determined by basic engineering studies.

e) There is need for the establishment of a plan for such a state-wide system of freeways and expressways determined without regard to present jurisdiction over the highways, roads, and streets that might be included, in order that appropriate state, county, and city transportation plans and fiscal arrangements may be worked out and properly coordinated; now, therefore, be it

Resolved by the Senate of the State of California, the Assembly thereof concurring, As follows:

a) The Department of Public Works is requested to undertake a study which will provide a basis for an over-all state-wide plan of freeways and expressways for the State of California, such study not to be limited to state highways and such study to locate the potential freeway and expressway routes of such a state-wide system and the necessary connections thereto as nearly as is practicable in advance of detailed engineering design of projects.

b) The Department of Public Works is requested to employ by contract or otherwise such engineering consultants or other specialists as it deems may be needed for conduct of the study and the preparation of reports.

c) The Department of Public Works is requested to defray the costs of the study from moneys available in the State Highway Fund for highway planning and is further requested to undertake to secure matching contributions of federal funds available for highway planning to the extent that such are available.

d) Agencies of the State Government and cities and counties and the City and County of San Francisco are requested to cooperate with the Department of Public Works in the conduct of the study.

e) The Speaker of the Assembly and the President pro Tempore of the Senate are directed jointly to appoint a committee of seven officials of counties and seven officials of cities to act in a technical advisory capacity to the Department of Public Works, and the department is directed to cooperate and confer with the technical advisory committee so appointed.

f) The Speaker of the Assembly and the President pro Tempore of the Senate shall refer the subject matter of this resolution to the appropriate joint interim committee which may deal with highway transportation problems if such committee is created at this session of the Legislature, or if no such committee is created, then the subject matter shall be referred to the appropriate interim committee of each of the respective houses by the Speaker and the President pro Tempore respectively.

g) The Department of Public Works is requested to report from time to time on the progress of its study to the appropriate interim committee or committees as designated under the provisions of the preceding paragraph and to submit its final report on the subject matter of this resolution to the appropriate committee or committees not later than September 1, 1958.

Senate Concurrent Resolution No. 134

WHEREAS, After full legislative consideration a program of additional financing of state highways was adopted by the Legislature in 1953 and extended in 1955; and

WHEREAS, Present taxes for highway purposes are scheduled for reduction in 1959; and

WHEREAS, The Federal-aid Highway Act of 1956 has been enacted providing California with certain additional funds for state highway construction; and

WHEREAS, Further congressional action on the federal highway program to be taken in 1958 will vitally affect the financing of California's highways; and

WHEREAS, Needs of county roads and city streets are directly related to the state highway program; and

WHEREAS, The Legislature in its 1957 Session has enacted Senate Concurrent Resolution No. 26 requesting the Department of Public Works to prepare, with the advice of a select committee of county and city officials, an engineering plan for a state-wide system of freeways and expressways, and to report its findings to a legislative interim committee by September 1, 1958; and

WHEREAS, The Legislature has need of the latest complete information on all of the foregoing matters so that it may enact legislation giving proper and balanced consideration to the problems of state highways, county roads, and city streets, particularly in respect to the extent of the program needed for each system and the methods of financing those programs; now, therefore, be it

Resolved by the Senate of the State of California, the Assembly thereof concurring, As follows:

1. The Joint Interim Committee on Highway Problems is hereby created, appointed, authorized, and directed to ascertain, study, and analyze all facts relating to the following:

a) California's highway, road, and street needs, including an appraisal of all deficiencies with respect thereto;

b) The efficiency and effectiveness of state highway, county road, and city street expenditures, including a determination of whether unnecessary, wasteful or extravagant expenditures have been or are being made by any agency of government;

c) Budgetary practice relating to highways, roads, and streets of the State, counties, and cities;

d) The effectiveness and efficiency of present administrative arrangements pertaining to highways, roads, and streets;

e) The effectiveness of present policies of the state and local agencies with respect to advance planning of highway construction and the advance acquisition of rights of way;

f) The costs and economic effects of present policies with respect to the construction of limited access highways and metropolitan freeways;

g) The desirability of establishing a system of freeways and expressways;

h) Alternative methods of financing the highway, road, and street modernization programs of California;

i) Alternative methods of taxing heavy commercial vehicles equitably in relation to taxes on other highway users, including consideration of the impact and revenues derived from the motor vehicle transportation license tax and alternatives therefor;

j) The collection and evaluation of data which will provide an equitable basis for the allocation of funds for highway purposes among the various levels of government in this State and among the geographic areas of the State;

k) The effect of federal aid for any class or classes of highways, roads, and streets in this State, together with the related effects on other highways, roads, and streets, including the possibility of reapportioning funds allocated for highways on which increased federal aid is available for use on other highways, roads, and streets.

2. The committee shall consist of the President pro Tempore of the Senate and six other Members of the Senate appointed by the Committee on Rules thereof. Vacancies occurring in the Senate membership of the committee shall be filled by the Senate Committee on Rules. The committee shall also consist of the Speaker of the Assembly and six other Members of the Assembly appointed by the Speaker thereof. Vacancies occurring in the Assembly membership of the committee shall be filled by the Speaker or, if there be no Speaker, by the Assembly Committee on Rules.

3. The committee is authorized to act during this session of the Legislature, including any recess, and after final adjournment until the commencement of the 1959 Regular Session, with authority to file partial report not later than the fifteenth of March, and its final report no later than the last day of that session.

4. The Committee and its members shall have and exercise all of the rights, duties, and powers conferred upon investigating committees and their members by the provisions of the Joint Rules of the Senate and Assembly as they are adopted and amended from time to time, which provisions are incorporated herein and made applicable to this committee and its members.

5. The committee has the following additional powers and duties:

a) To select a chairman and a vice chairman from its membership;

b) To employ an executive secretary, engineers, auditors, and other personnel as it deems necessary to carry out the purposes for which it is created;

c) To contract with such other agencies, public or private, as it deems necessary for the rendition and affording of such services, facilities, studies, and reports to the committee as will best assist it to carry out the purposes for which it is created;

d) To cooperate with and secure the cooperation of county, city, and county, and other local law enforcement agencies in investigating any matter within the scope of this resolution and to direct the sheriff of any county to serve subpenas, orders, and other process issued by the committee;

e) To collect by questionnaires, direct investigation, or otherwise, all such information from the owners and operators of motor vehicles on the highways, roads, and streets of this State as it deems necessary in order to formulate a reasonable and equitable system of highway user taxation for all classes of motor vehicle operation and to carry out the other purposes for which it is created;

f) To report its findings and recommendations to the Legislature and to the people from time to time and at any time not later than herein provided;

g) To meet and act at any place within the State or within the United States;

h) To do any and all other things necessary or convenient to enable it fully and adequately to exercise its powers, perform its duties, and accomplish the objects and purposes of this resolution.

6. The committee is authorized in its discretion to appoint an advisory council to consist of nonlegislative members, but which shall include representatives of major state-wide public and private agencies and organizations having a primary interest in streets and highways, as may be determined and appointed by the committee, which council shall aid and advise the committee in the studies conducted by the latter in carrying out the purposes of this resolution. The advisory council shall have and exercise such powers and duties as shall be defined from time to time by the committee within the scope of the powers and duties committed to the latter by this resolution.

7. The sum of fifty thousand dollars ($50,000) or so much thereof as may be necessary is hereby made available from the Contingent Funds of the Senate and Assembly for the expenses of the committee and its members, and for any charges, expenses or claims it may incur under this resolution, to be paid from said contingent funds equally and disbursed, after certification by the chairman of the committee, upon warrants drawn by the State Controller upon the State Treasurer.

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

PAVEMENT DESIGN PRACTICES IN VIRGINIA

K. E. Ellison,[1] F. ASCE

ABSTRACT

Virginia utilizes a modified CBR method for designing highway pavements. The primary and Interstate Systems are divided into 6 classes based on the weight and volume of truck traffic. Design wheel loads vary from 9,000 to 24,000 pounds depending on anticipated traffic. Similarly the secondary system is divided into 4 classes with wheel loads varying from 4,000 to 12,000 pounds.

Primary and Interstate Highways

Highway pavements are constructed to provide support for loads imposed by anticipated traffic. The pavements must provide a firm, stable and smooth surface at all times. In order to do this, the quality and thickness of the pavement must be such that it will have sufficient stability to withstand the traffic loads under all weather conditions. Coordination of the factors of design, construction, and maintenance are essential to produce the pavements. Of these three factors, design is of primary importance. Excellent construction and maintenance procedure cannot overcome deficiencies in design, particularly when inadequate thicknesses of pavement are provided.

Approximately 30 different methods of pavement design are being used in the United States at the present time. Some of these methods (Virginia's included) are based on field and laboratory studies while others are based more or less on rule of thumb evolved from experience. Theoretical solutions of the design problem is difficult because of the many complex variables involved. These variables include:

Note: Discussion open until February 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2145 is part of the copyrighted Journal of the Highway Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. HW 3, September, 1959.

1. Asst. Materials and Tests Engr., Virginia Dept. of Highways, Richmond 19, Va.

1) Rapidly increasing loads both in volume and weight.

2) Measuring the supporting power of the subgrade.

3) The effect of repeated loadings.

4) The effect of varying climatic conditions.

5) The structural strength of the pavement.

6) Construction procedures used.

In designing pavements, cost is a very important factor. However, attention must be given to providing designs that will give adequate traffic service under all climatic conditions. The vehicle operator expects to use the road during all seasons of the year and is very much concerned with the smoothness of the surface. A rough, distorted or patched pavement is a poor road as far as the driver is concerned even though the geometric features are excellent.

In designing pavements a great deal of data must be assembled and evaluated before an intelligent design can be made. Before proceeding further it may be well to review the definition of various terms used. In this paper the following definitions will be used.

Pavement. The pavement is the entire road structure excluding the subgrade. It includes the subbase, base and surface.

Subgrade. The subgrade is immediately below the pavement. It can either be the natural soil or it can be a selected material.

Subbase. The subbase consists of a granular material which is of higher quality and has a higher bearing value than the subgrade. It is an intermediate course placed between the subgrade and the base course. Its purpose is to provide drainage and to minimize the effect of subgrade volume change.

Base. The base is composed of materials of sufficient structural quality and thickness to withstand the forces of wheel loads. It is resistant to volume changes or softening due to climatic conditions or moisture fluctuations, and it is resistant to vertical pressures from loads which tend to distort the surface.

The surface course. The surface course consists of materials that waterproof the base, protects the base from raveling and disintegrating effects of traffic and increases the load supporting value of the entire structure.

With these definitions in mind, the following is a step by step outline of the procedure used in designing pavements.

The first step, of course, is the soil survey. In order to conduct the soil survey, certain minimum information is required. This information includes the ground line, the proposed tentative grade and a plan showing the location on the ground and the property owners. Soil surveys are conducted, generally, in accordance with AASHO Designation T86-54. No hard and fast rules can be established for conducting a soil survey, however, the minimum plan will include:

1) Obtain representative samples of soil for tests.

2) Determine and define the limits represented by those samples both horizontal and vertical. In order to do this, it will be necessary to make borings approximately every 200 feet, or oftener if necessary, along the proposed center line, to depths of 5 feet below the proposed grade or to where rock is encountered.

3) Determine the depth to rock if within the limits of exploration. This information is supplemented by an Electrical Resistivity survey on the right and left limits of construction. This method measures the resistance which a material will offer to a given electrical current. By correlation with the known geology and the results of the soil survey, an accurate rocksoil profile can be developed.

4) Determine whether or not underground water is present and the depth at which encountered. Moisture samples are obtained so that the percent of moisture present can be compared with the optimum moisture content of the same material.

5) Inspect fill sections for evidence of soft or swampy conditions and if such conditions exist, to determine the depth of this material. Evaluate the load carrying capacity of the material in its natural state and make recommendations for construction embankments over the area. Where muck is encountered undisturbed samples are obtained and consolidation and other tests conducted. The decision is then made as to type of construction, i.e., muck excavation, sand drains, or displacement.

The second step is the testing and the evaluation of soil samples obtained from the soil survey. All representative soil samples obtained in the soil survey are tested in the laboratory for certain engineering characteristics. The soils are classified according to AASHO Designation M145. This classification is based on the sieve analysis, mechanical analysis, liquid limit, and plastic limit. Other standard AASHO Tests are used to determine the maximum density, optimum moisture, shrinkage limit, shrinkage ratio. Virginia's modified CBR Test is performed to determine the bearing value (CBR) which is applied to the proper design curve to find the required pavement thickness. The modification in the CBR Test, as used in Virginia, is in the applied compactive effort. It was decided when this method was adopted to use for the test the density that most nearly met field conditions. Since our construction specifications require fills and subgrades to be compacted to a minimum of 95 percent of theoretical density as determined by AASHO Designation T99 standard Proctor density was selected for the test.

The information obtained on the soil survey is the basis for the pavement design. In flexible pavement design the CBR value of the soil and the AASHO soil classification will determine the total thickness of select subgrade, subbase, base, and surface. The subgrade design is made simultaneously with the pavement design. The thickness of selected subgrade material will vary according to the CBR value of the soil-in-place. The subbase, base, and surface will then be uniform for the project.

In many areas of the state suitable select subgrade material is not available within a reasonable haul for reasonable costs. In these areas it will be necessary to improve the bearing value of the natural soil with some additive such as cement or lime. Cement or lime treated subgrades are relatively new in Virginia but have been carried out successfully in other states. Experimental work conducted by our Research Division indicates that very good results should be obtained from this type of construction. A brief explanation of this type of construction might be in order at this time. A low percentage of lime or cement is mixed with the subgrade to whatever depth is necessary to satisfy the design requirements. The addition of lime or cement changes the characteristics of the soil and increases the load carrying capacity of the soil. The subbase, base and surface is then constructed on the treated subgrade.

Factors other than the CBR value of the soil-in-place will also affect the thickness of the select subgrade. Sections containing saturated soils (indicating underground water) will require special attention. An additional depth of selected subgrade material may be indicated based on the amount of water plus the classification of the soil. Other corrective measures may also be taken including undercutting, installation of pipe underdrains, and grade changes.

In the design of rigid pavements the CBR value of the soil is used to obtain an approximate value of k (Modulus of subgrade reaction). The AASHO soil classification is used to determine whether or not a subbase material, to prevent pumping, is required.

The next step in the design procedure is the evaluation of traffic. Traffic information is obtained by the Traffic and Planning Division. Traffic density has a decided influence on flexible pavement performance. Safeguards must be taken to prevent failure in the form of cracking and breaking up due to fatigue resulting from the continual flexing or bending of the pavement structure under passing wheel loads. Additional stiffness in the pavement is provided by an additional depth of granular subbase or selected subgrade material over plastic soils, or soils with low bearing or resistance value. For design purposes, the traffic is divided into six categories based on the estimated daily volume of trailer trucks and buses. These traffic categories are as follows:

Estimated Daily Traffic Trailer Trucks & Buses	Traffic Category	Factor
0-19	I	0.75
20-199	II	1.00
200-699	III	1.25
700-1499	IV	1.50
1500-2499	V	1.75
2500 and over	VI	2.00

The wheel load used in pavement design varies according to anticipated traffic volume.

The following empirical formula is used to account for the frequency and character of traffic loads.

$$\text{Designed wheel load} = 12{,}000 \times \text{Factor}$$

The factor referred to is the factor shown in the table above. The factor increases as the volume of traffic increases. It would be erroneous to design a pavement that would be built in the future, based on today's traffic volume. The design must include future anticipated traffic. For flexible pavements, the design is for traffic anticipated 20 years in the future. It has been estimated that commercial traffic in Virginia will increase approximately 5 percent per year. Consequently, in designing pavements for primary roads, current commercial traffic is increased by 100 percent in order to obtain the proper traffic category.

The accompanying design chart gives the total depth of subbase, base and surface in inches for each traffic category. It is based on the design wheel load, plus 20 percent for impact load.

At first glimpse, it might appear that the allowance for traffic density is excessive. This is not the case. As an example, compare the total depth of select subgrade material, subbase, base and surface required for a soil with a CBR value of 5 for a route classified in category II with a route classified in category VI. A route classified in category II, 20 to 199 trailer trucks and buses per day would require 17 inches of select subgrade, subbase, base, and surface. A route classified in category VI, 2,500 or over trailer trucks and buses per day would require 25 inches of select subgrade, subbase, base, and surface. This is a difference of 8 inches or an increase of 47 percent in the total thickness required for an increase in heavy vehicle traffic of over 1,000 percent.

The last step is the subgrade and pavement design. In Flexible Pavements the total thickness of select subgrade, subbase, base, and surface is determined by the CBR value and AASHO classification of the soil in conjunction with the traffic category. Once this total thickness has been established the actual depths of the separate increments will depend on several other influencing factors. These include:

1) Quality and character of selected subgrade material.

2) Quality and character of subbase material.

3) The volume and character of anticipated traffic.

4) The elevation of the pavement in relation to the water table. The designer will take into account all of the above factors and will determine the depth of each increment based on judgement and experience.

In the design of Rigid Pavements it is not contemplated that a select subgrade material will be used except in special cases. Select subgrade may be used in areas containing soils with high volume change or in sections containing mucky or highly saturated soils. The depth required will be dictated by soil classification tests and by moisture content of the soil-in-place.

The depth of subbase required to prevent pumping will be dictated by soil classification tests. This depth, however, rarely exceeds 4 inches of high type crushed aggregate material or 6 inches of soil aggregate material.

The depth of pavement will be determined by the k value of the soil and the weight and frequency of wheel loads. The Concrete Pavement Design Manual published by the Portland Cement Association is used as the design manual. The anticipated traffic is divided into weight groups. The number of load repetitions are computed for each weight group for the life of the pavement or 30 years. When the number of load repetitions exceed 100,000 for the life of the pavement, a safety factor of two is used. (A safety factor of two means that the designed flexural strength is 350 pounds per square inch instead of 700 pounds per square inch.) When the anticipated load repetitions are less than 100,000 for any weight group, a safety factor of between one and two is used.

Virginia's current method of pavement design has been in use about 9 years. In those 9 years approximately 700 projects have been designed for primary roads. We have tried to avoid the need for greater pavement depths, and consequently, greatly increased costs by increasing the thickness and quality of selected subgrade material. The selected subgrade material being less expensive than the pavement items.

Possibly the greatest advance in pavement design in Virginia and other states as well, has been in the design of shoulders. The current plan is to

pave the entire roadbed from ditch to ditch. This was probably brought about by the desire to avoid the old type of trench construction. At least three very beneficial results are derived from paving the entire roadbed. First, adequate subgrade drainage is provided. Second, lateral support for the pavement is provided, and third, a shoulder is provided that will afford an area for emergency stops under all weather conditions.

Secondary Roads

Secondary Roads in Virginia are constructed mainly for two purposes:

1) Farm to market roads.

2) Subdivision streets.

In June of 1958 the Department prepared standard designs for secondary roads.

General

For design purposes, secondary roads have been divided into four classes as follows:

Class I
0 to 200 vehicles per day
a. Under 50 vehicles per day
b. 50 to 200 vehicles per day

Class II
201 to 400 vehicles per day

Class III
401 to 1,000 vehicles per day

Class IV
Over 1,000 vehicles per day
a. 1,001 to 4,000 vehicles per day
b. Over 4,000 vehicles per day

Typical pavement designs for each class of secondary roads is included. These are to be used as a guide. Other combinations than those given may be used. Pavement designs should fit local conditions.

When it is possible, surface courses should be omitted from the initial contract. This cannot be done, however, when the road has been surface-treated prior to reconstruction.

When a surface treatment is to be included in the original contract, it is suggested that the second seal be withheld for approximately one year and be accomplished by Contract II.

Base Course

There is a choice of several types of base material. These types are similar to AASHO Designation M-147.

Type I - Crushed aggregate base material grading A, B, C, or D

Type II - Soil aggregate base material grading C, D, E, or F

Flexible Pavement Design Chart
Total Depth in Inches
Traffic Category

CBR Value of Soil	I	II	III	IV	V	VI
1	36	40	44	52	60	70
2	25	28	31	37	43	50
3	20	22	25	28	32	36
4	17	19	21	24	27	30
5	15	17	19	21	23	25
6	14	16	17	19	21	23
7	13	15	16	17	19	21
8	12	14	15	16	18	20
9	11	13	14	15	17	19
10	10	12	13	14	16	18
11	9	12	13	14	15	17
12	9	11	12	13	14	16
13	8	11	12	13	14	15
14	8	10	11	12	13	14
15	7	10	11	12	13	14
16	7	9	10	11	12	13
17	7	9	10	11	12	13
18	7	8	9	10	11	12
19	6	8	9	10	11	12
20	6	7	8	9	10	11
21	6	7	8	9	10	11
22	6	7	8	9	10	11
23	6	7	8	9	10	11
24	6	7	8	9	10	11
25	6	7	8	9	10	11
30	4	6	7	8	9	10
35	4	6	7	8	9	10
40	4	6	7	8	9	10
45	4	6	7	8	9	10
50	3	6	7	8	9	10

When crushed aggregate base material is specified, the coarser gradings (grading A or B) are preferable.

When soil aggregate is specified, grading C or D should be selected when a commercial material is to be provided.

If local material is available, grading E or F should be specified in most cases.

When soil aggregate grading E or F is specified, an additional two-inch depth of base should be provided.

When it is possible to do so, alternate types of bases should be set up. This will attract more bids and will result in more economical construction costs. When soil cement is shown as an alternate base, the surface course should be included in the original contract for all alternates.

When surface course is not included in the original contract, the base material should be treated with calcium chloride at the rate of one-half pound per square yard per inch of depth.

Select Material

In several of the typical designs select material is shown as replacing part of the base material. In general, the specifications for this select material should be similar to the specifications provided for the select material used on the Interstate System. These specifications are; maximum size 3 inches, must be reasonably well graded from coarse to fine with not more than 25 percent passing the No. 200 sieve. The liquid limit shall be not greater than 30 and the plasticity index shall be not greater than 9. The CBR value shall be not less than 30 or as specified.

All designs included herein are based on a subgrade with a CBR value of 10. For those sections of a project having a subgrade with a CBR of less than 10, capping material with a minimum CBR value of 10 should be provided. Where the CBR value is greater than 15 the depth of pavement can be reduced accordingly.

Examples of Typical Pavement Designs

Class I*

0 to 200 vpd
Design wheel load 4,000 pounds
Minimum CBR of subgrade 10

a. Under 50 vpd
   1. Base - 6 inches base material
      Surface - none (apply calcium chloride)
   2. Subbase - 4 inches select material
      Base - 3 inches base material
      Surface - none (apply calcium chloride)

b. 50 to 200 vpd
   1. Base - 6 inches base material
      Surface - prime and double seal
   2. Base - 6 inches soil cement stabilization
      Surface - prime and double seal

*Should there be a disproportionate number of passenger vehicles or trucks on any road, the thickness of the base is to be adjusted accordingly.

3. Subbase - 4 inches select material
   Base - 3 inches base material
   Surface - prime and double seal

Class II*
201 to 400 vpd
Design wheel load 6,000 pounds
Minimum CBR of subgrade - 10
1. Base - 8 inches base material
   Surface - prime and double seal
2. Base - 8 inches soil cement stabilization
   Surface - prime and double seal
3. Subbase - 6 inches select material
   Base - 4 inches base material
   Surface - prime and double seal

Class III*
401 to 1,000 vpd
Design wheel load 8,000 pounds
Minimum CBR of subgrade - 10
1. Base - 8 inches base material
   Surface - prime, mixed-in-place, and seal
2. Base - 8 inches base material
   Surface - light penetration surface course (approximately 100 pounds)
3. Base - 8 inches soil cement stabilization
   Surface - prime, mixed-in-place, and seal
4. Base - 8 inches soil cement stabilization
   Surface - light penetration surface course (approximately 100 pounds)
5. Subbase - 6 inches select material
   Base - 4 inches base material
   Surface - prime, mixed-in-place, and seal
6. Subbase - 6 inches select material
   Base - 4 inches base material
   Surface - light penetration surface course (approximately 100 pounds)
7. Base - 8 inches base material
   Surface - Prime at the time of construction 150 pounds bituminous concrete on Contract II.
8. Subbase - 6 inches select material
   Base - 4 inches base material
   Surface - prime at the time of construction 150 pounds bituminous concrete on Contract II.

Class IV
Over 1,000 vpd
a. 1,000 to 4,000 vpd
   Design wheel load 10,000 pounds
   Minimum CBR of subgrade - 10
   1. Subbase - 6 inches base material
      Base - 3 inches penetration macadam
      Surface - Mixed-in-place, choke, and seal

*Should there be a disproportionate number of passenger vehicles or trucks on any road, the thickness of the base is to be adjusted accordingly.

2. Subbase - 6 inches base material
   Base - Prime, 275 pounds (2-1/2") H-3(1) Bituminous Concrete
   Surface - 165 pounds bituminous concrete
3. Subbase - 4 inches select material
   Base - combination, 3 inches base material, 3 inches penetration macadam
   Surface - mixed-in-place, choke, and seal
4. Subbase - 4 inches select material
   Base - 3 inches base material
   Surface - prime 275 pounds H-3 (1) (Bituminous Concrete) and 165 pounds bituminous concrete
5. Subbase - 6 inches select material
   Base - 6 inches base material
   Surface - mixed-in-place, choke, and seal.
6. Subbase - 6 inches cement or lime treated subgrade
   Base - 6 inches base material
   Surface - mixed-in-place, choke and seal

b. Over 4,000 vpd
   Design wheel load 12,000 pounds
   Minimum CBR of subgrade - 10
   1. Subbase - 8 inches base material
      Base - 3 inches H-3 (1) (Bituminous Concrete)
      Surface - 165 pounds bituminous concrete
   2. Subbase - 5 inches cement or lime treated subgrade
      Base - combination, 3 inches base material and 3 inches H-3 (1) (Bituminous concrete)
      Surface - 165 pounds bituminous concrete
   3. Subbase - 6 inches select material
      Base - combination 3 inches base material and 3 inches H-3 (1) Bituminous Concrete
      Surface - 165 pounds bituminous concrete

For curb and gutter sections
In accordance with traffic, taking into consideration the volume of truck traffic.

Journal of the
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

THE ELECTRONIC COMPUTER IN HIGHWAY ENGINEERING

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ABSTRACT

This paper describes electronic computers and their functional components; the way in which they operate; the procedure for using them in the solution of engineering problems; and applications to highway engineering problems. A brief bibliography is included.

FOREWORD

This is the first of a series of papers, prepared under the sponsorship of the Committee on Increasing Highway Engineering Productivity of the Highway Division, to provide information on electronic computers and other devices and techniques which are proving effective in increasing engineering productivity in the highway field. In this way, the Committee hopes to accomplish, in part, the purpose for which it was established and to assist highway and highway bridge engineers in gaining a working knowledge of the nature and potentialities of new and improved methods and devices for application in their individual spheres of professional endeavor.

INTRODUCTION

Only about four years ago, the electronic computer was virtually unknown in the highway and highway bridge engineering fields. Today, all but a few of the State highway departments are using electronic computers in their day-to-day engineering work. They have installed their own computers, trained their engineers to use them, and have established computer staffs to operate them.

Note: Discussion open until February 1, 1960. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. Paper 2146 is part of the copyrighted Journal of the Highways Division, Proceedings of the American Society of Civil Engineers, Vol. 85, No. HW 3, September, 1959.

1. Chf. Electronics Branch, Div. of Development, Office of Operations, Bureau of Public Roads, U. S. Dept. of Commerce.

Consulting firms engaged in highway and bridge engineering also have been quick to recognize the advantages inherent in electronic computation and more and more of them are turning to this new device. Electronic computation is now well established and is fast becoming standard practice in highway and bridge engineering organizations.

In view of the capabilities of the electronic computer, it is not surprising that there has been this rapid and broad acceptance of it. A large part of engineers' time is consumed in the processing of field and laboratory data and in performing computations involved in research and development, planning, location, design, construction, and estimation. Much of this computation is routine and repetitive and, in itself, adds nothing to the engineer's proficiency. Also, with few exceptions, the time required to complete an analysis or to advance an approved project to the construction stage is determined by the time required to process data and to perform the necessary computations. At times, the sheer magnitude of the computing job forces the engineer to limit his investigation and base his findings on data and analyses which are not as complete as they could be. In other instances, needed engineering and economic studies are deferred or not undertaken at all because of the seemingly prohibitive volume of data processing and computation involved.

In the electronic computer, the engineer has found the remedy for these difficulties—a device which can process data at amazing speeds and perform literally thousands of arithmetic operations per minute with perfect accuracy and without his supervision.

Types of Computers

All computing machines or devices, whether or not they operate electronically, fall into two general categories—analogue and digital. The basic difference between them is that the analogue computer handles data in the form of measurements of physical variables while the digital computer uses numbers in digital form. Each has its field of application and a substantial record of achievement, both of which have broadened substantially with the advent of the electronic computer.

Analogue Computers

In the analogue computer, numbers or quantities are represented analogously—by lengths along a scale, shaft rotations, electric currents or voltages, etc. The slide-rule is an example of an analogue computer in which numbers are represented by lengths along a scale. An example in which shaft rotations are used is found in the automobile speedometer. Rotations of the drive shaft are converted to a visual indication of the speed of the vehicle. Other examples of non-electronic analogue computers include planimeters, nomograms, household watt-hour meters, thermostats and many other devices in common use.

Most electronic analogue computers represent numbers or quantities by direct current voltages. The electronic circuitry of the computer is arranged to simulate mathematically the problem to be solved or the physical system under study. The input voltages, representing numerical values for the constants and variables involved, are adjusted or modified by means of potentiometers to correspond to the varying conditions to be analyzed. Answers are

read on mechanical indicating dials, displayed on cathode-ray tubes or drawn by pen recorders. While electronic analogue computers may be and sometimes are constructed as general purpose computers, more frequently they are special purpose devices, that is, they are designed for the solution of a particular problem. They are particularly valuable in solving dynamic problems in which the input values vary continuously with respect to time. More and more applications are being developed in process control and industrial automation, as well as in scientific and engineering problems. However, because of the limitations involved in physical measurement, it is difficult to attain a precision greater than three or possibly four significant figures. For this reason, the electronic analogue computer has not been considered as useful for highway and bridge engineering problems as its digital counterpart.

Digital Computers

In the digital computer, practically any degree of precision consistent with the precision of the source data can be attained simply by specifying the number of decimal places to be used.

The general purpose electronic digital computer is the type of computer which is proving to be so valuable in highway and bridge engineering and is the one with which the remainder of this discussion is concerned. As stated previously, in a digital computer, numbers are represented in terms of their digits. The venerable abacus, still rendering good service in parts of the world, adding machines, desk calculators and bookkeeping machines are examples of non-electronic digital computers.

The first electronic digital computer was developed at the Moore School of Electrical Engineering of the University of Pennsylvania for the Ballistic Research Laboratories of the Army Ordnance Department. This machine, called the ENIAC (Electronic Numerical Integrator and Computer), was completed and placed in service at the Aberdeen Proving Ground in January 1947. This marked the beginning of the widespread use of electronic digital computers. Subsequent development was intensive and rapid with substantial advances in speed, capacity, reliability and versatility. The first machine to be mass produced was the UNIVAC (Universal Automatic Computer) made by what is now the Sperry Rand Corporation. This computer was placed on the market in 1951. Others followed and today many makes and models are available, mostly of the general purpose type.

Not all of these computers are the large, costly machines commonly referred to in the popular press as "giant electronic brains." Rather, they cover a variety of sizes, ranging from the North American Aviation Company's fully transistorized RECOMP which occupies about five cubic feet of space to the large systems such as the International Business Machines Corporation's Model 704 which requires about 3000 square feet of floor space. Between these extremes, there are a number of others which approximate in size an office desk or file cabinet.

However, regardless of size, they all do essentially the same things—they add, subtract, multiply and divide. In this respect, they are similar to the desk calculator except, of course, that they employ electronic circuitry. Also, they differ from the desk calculator in that they can store large quantities of information, they can compute at tremendous speeds, they can perform automatically long series of arithmetic operations in predetermined order without

human intervention, and they can make simple logical decisions by comparing one number with another and following either of two courses of action depending upon which number is the larger.

The high computing speeds are the result of using electronic circuitry to perform arithmetic operations—no wheels, levers, cams or other mechanical devices are used and consequently the limitations inherent in mechanical systems are not involved.

Of even greater importance than speed in the computer's ability to carry out long sequences of arithmetic operations automatically. This is done through a process called "programming" which is explained in detail further on in this discussion. Briefly, programming consists of reducing the problem to be solved to elementary arithmetic operations and then preparing a series of instructions for the computer to follow in performing these operations in proper order. The entire set of instructions for a particular type of problem is the computer program, or simply the "program" for that problem. Once completed, it may be used over and over again, whenever that type of problem is to be solved. Most modern computers are referred to as "stored program machines" which means simply that the program being used is stored in the computer along with the problem data.

The decision making feature is valuable in making provision for the automatic following of one of a number of alternate courses depending upon given conditions or upon conditions which appear in intermediate results as the computation progresses. This is done, for example, in repeated segments of the program a prescribed number of times, in determining degree of convergence in function evaluation, in table look-up or search operations, and in a number of other situations encountered in the automatic solution of a problem.

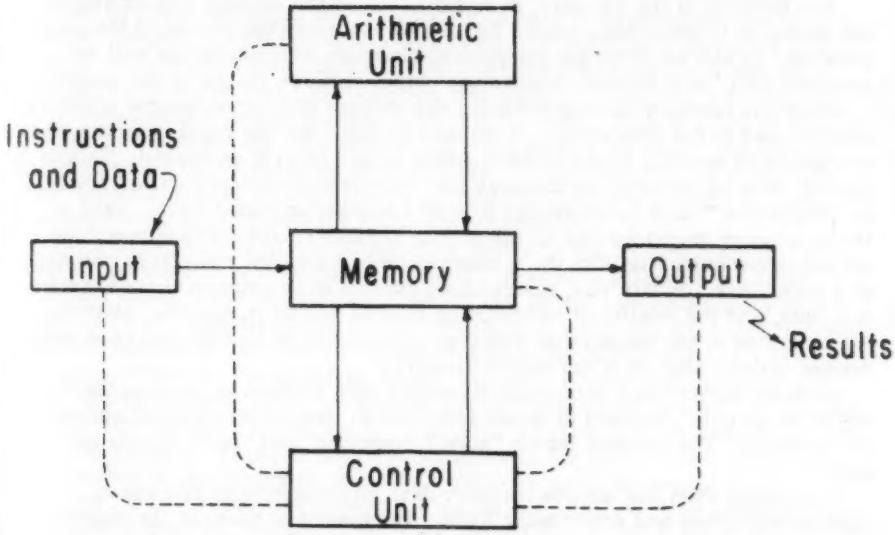
Component Parts

While the detailed arrangement and construction of general purpose, stored program, electronic digital computers vary, the basic functional components are essentially the same. These may be represented schematically as shown in Figure 1.

Input

The function of the input is to place problem data and program instructions in the memory of the computer. The technical term for this operation is "reading." Both types of information are recorded in advance on punched cards, punched paper tape or magnetic tape depending upon the input facilities of the computer being used. Some computers will accept information only from punched cards, others only from punched paper tape or only from magnetic tape and still others from all three media.

Problem data are recorded on punched cards by punching holes in various positions in the vertical columns of the card. Instructions are recorded similarly using a numerical code. On paper tape, both types of information are represented by code patterns of the presence or absence of holes across the width of the tape. The holes and spaces are positioned in parallel channels running the length of the tape. Depending upon the code used, there may be from five to eight such channels. Information is recorded on magnetic tape in a somewhat similar fashion using magnetized spots instead of holes.



Typical Arrangement of Electronic Digital Computer Functional Components

Figure 1

Provision is also made for entering instructions and data by means of manually operated switches on the computer itself, a numerical keyboard, or the keyboard of a specially connected electric typewriter.

The punched cards or punched paper tape are read by metallic brushes or photoelectric cells. As the cards or tape pass through the reader, a circuit is closed each time a hole appears and a pulse of current enters the machine. For magnetic tape, an electromagnetic reading device is used.

For problems in which there is a large volume of input data, efficient operation of the computer requires that input data be read into the computer as rapidly as possible. Magnetic tape is much the fastest input medium with reading speeds up to about 50,000 characters per second. Where source data is on punched cards, card to tape converters can be used to transfer the data to magnetic tape. Since the converter is an independent machine, this can be done while the computer is otherwise engaged.

Memory

The function of the memory, sometimes called the storage unit or simply the store, is to store information for use as needed in the course of the computation. In stored-program computers, program instructions as well as problem data, intermediate results and output data are stored in the memory.

Since the memory must provide for the storage of a large volume of information used in the computation, provision is made for the rapid insertion and extraction of specific items of information in and from it as needed. This is usually done by dividing the memory into segments, commonly called "cells" or "registers," each large enough to hold a number in coded form. Each of these memory registers has an identifying number called its "address," an arrangement somewhat like the numbered cubby holes for room keys and mail at a hotel desk. In this way, instructions expressed in numerical code, problem data, and the results of computation may be stored in specific, identifiable locations in the memory so that they can readily be located and read when needed without searching the entire memory.

Memory devices are commonly classified with respect to "access time" which is the time required to locate and read an item of information stored in the memory. The relative terms "slow," "medium" and "fast" access are used.

Commonly used fast access memory devices include magnetic cores, cathode-ray tubes and sonic delay lines. The fastest of these is the magnetic core matrix which has an access time of a few millionths of a second. A magnetic core is a tiny toroid (about 2 mm. in diameter) made of a ferro-magnetic material. The cores are strung on wires in matrix form with one wire running from top to bottom through each column and a second wire running from side to side through each row. A third wire passes diagonally through each core. By sending current through a pair of wires, one horizontal and one vertical, the core located at their intersection can be magnetized. By passing current through selected pairs of wires, a number can be stored in the form of a code pattern of magnetized and non-magnetized cores or of positively and negatively magnetized cores. Many numbers can be stored in this way in a single core matrix. The total memory unit consists of a number of connected matrices. Information is read from the magnetic core memory through the diagonal wire, sensing the magnetic state of each core in the group comprising a memory register.

The cathode-ray tube memory unit consists of a bank of tubes similar to the picture tubes used in television sets but smaller. Information is stored on the faces of the tubes in the form of spots of electrostatic charge. Something over a thousand such spots can be stored on a three-inch tube face. Information is recorded in a specified memory register on the face of a tube by directing a beam of electrons toward the spot bearing that address. In reading stored information, the electron beam is directed toward the memory register involved producing a change in the charge stored there which is detected by a capacitive coupling to a conducting surface placed against the face of the tube on the outside. Like the magnetic core memory, the cathode-ray tube access time is a few millionths of a second.

In the sonic delay line type of memory, also called an acoustic delay line, series of electrical pulses representing in code pattern the information to be stored, are transformed to a train of sound waves in a physical medium such as a tube of mercury. At the receiving end of the line, the sound waves are

converted back to electrical pulses, simplified, reshaped and fed back into the mercury line at the other end as sound waves. This is a continuous process by means of which the information is kept circulating for use as needed. Information stored in this way is read at the output end of the line through the use of an address which specifies the time position in the wave train of the item desired. The address also identifies which of a number of lines comprising the total memory unit is to be used. This is a cyclic type of storage in which access time depends on the length of the delay line and the speed of sound in the physical medium used. While classified as a fast access memory device, access time is appreciably longer than for the non-cyclic magnetic core and cathode-ray tube types of memory.

The most widely used type of memory device is the magnetic drum. This consists of a non-magnetic metal cylinder coated with magnetic material, usually a nickel alloy or iron oxide, which will accept and retain information in the form of magnetized spots. The magnetized spots are arranged in code patterns similar to the pattern of magnetized cores in the magnetic core memory. While the computer is in use, the drum rotates continuously at a high, constant speed. Electromagnets, called "read-write heads" are mounted on a casing surrounding the drum and positioned about a thousandth of an inch from its surface. These are ranged along the length of the drum and at intervals around its periphery so that as the drum rotates, information can be "written" in or "read" from any of the memory registers. The registers are arranged in parallel tracks or bands around the drum. Each track has at least one read-write head. Sometimes, more than one head is used on a single track to reduce access time.

When one of the electromagnets is energized by an electrical impulse, the spot on the drum surface which is under the electromagnet at that instant is magnetized. If no current is flowing in the coil of the electromagnet, no magnetization takes place. In the reading process, when a magnetized spot passes under one of the electromagnets, a voltage pulse is induced in the coil—exactly the reverse of the writing process. A typical magnetic drum memory unit for an intermediate size computer may have as many as 4000 memory registers. Like the sonic delay line, the magnetic drum provides a cyclic type of storage. Access time, which depends on the speed of drum rotation, is a few thousandths of a second—the medium speed category.

Another medium access time memory device utilizes a rotating disk instead of a cylinder. Information is stored on the surface of the disk in concentric circular channels, each channel containing a number of memory registers. The surface of the disk is coated with ferro-magnetic material and the read-write operations are similar to those used with magnetic drums.

Multiple desk units are used to provide large memory capacity. For example, the IBM RAMAC (Random Access Method of Accounting and Control) utilizes fifty disks on a vertical shaft providing a total of 50,000 memory registers each capable of holding 100 digits and each having an identifying address. An access arm, carrying read-write heads, moves automatically up and down, and in and out, to reach any specified address. A number of those units can be integrated into a computer system to provide still greater memory capacity.

Magnetic tape has already been mentioned under "Input" and will be mentioned again under "Output." In addition to these two uses, it also serves as a memory device. While it is a very fast input or output medium, it is relatively slow as a memory device. However, because large volumes of data

can be stored in compact form at relatively low cost, magnetic tape is very valuable as auxiliary memory, supplementing the more costly, higher speed types of main memory. Also, it provides a permanent type of storage, that is, reels of tape containing stored data can be filed away until needed.

Magnetic tape is made of non-magnetic metal or plastic with a coating of iron oxide or other material which will accept and retain spots of magnetism. The magnetized spots are arranged in code patterns as in the case of the magnetic drum. Also electromagnet read-write heads used with magnetic tape are similar to those used with the magnetic drum. Information is recorded in blocks which are addressable usually by means of a serial indexing system. The tapes, commonly from one-half to one inch in width, are mounted on reels in tape handling units, a number of which can be used in combination. A reel may contain 2,400 feet or more of tape requiring several minutes to search from one end to the other.

To shorten the search time, multiple magnetic tape units have been developed. In these units, conventional tape reels are replaced by a number of shorter lengths of tape, as many as fifty in the Burroughs Corporation's Datafile, suspended loosely over guide rods in a bin. The length of each tape may be only a tenth of the length of the conventional reel tapes and the access time is correspondingly reduced. A number of multiple tape units can be wired into a computer system, giving a very large capacity.

Another magnetic tape storage device, the Clevite Corporation's Tape DRUM, uses a magnetic tape thirty inches in width, draped over a rotating drum. The read-write heads are mounted in the drum and rotate with it. The capacity of the section of the tape that can be scanned at one time, called a page, is comparable to the capacity of a magnetic drum. The full length of the tape contains a number of such pages, each of which can be moved into position to be scanned by the rotating heads. Access time within any one page is comparable to that of the magnetic drum type of memory, but additional time is, of course, required to move the desired page into scanning position.

The costs of memory devices are closely related to access time so that various combinations of storage media are used to provide both fast access and large capacity without excessive cost. The current trend in the large computers is toward the use of magnetic cores for the fast access main memory supplemented by magnetic drums, tape units or multiple disk units. The magnetic drum has become practically the standard memory device for the small and many of the intermediate size computers. Some of the latter have provision for auxiliary magnetic tape storage but, in many cases, the drum constitutes the entire memory.

In reading data from the memory, the stored information is not erased. A number stored in a memory register remains there unless it is replaced by a new number or unless the memory is cleared. However, in the case of power failure, information stored in "volatile" storage media such as electrostatic tubes and sonic delay lines, will be lost. "Non-volatile" storage media such as magnetic cores, drums, disks and tapes, retain stored information in the absence of power, ready for use when power is restored.

Arithmetic Unit

The arithmetic unit consists of electronic circuitry (electron tubes, transistors, diodes, etc.) by means of which the arithmetic operations of addition, subtraction, multiplication and division are performed. Also, it can shift

numbers right or left, transfer data from one memory register to another, modify program instructions and assist in logical decision operations.

The basic element of the arithmetic unit is the "adder," an electronic circuit designed to obtain the sum of two numbers. Subtraction is performed by using the adder to add one number to the complement of the other. Multiplication is accomplished by repetitive addition and shifting, and division by repetitive subtraction and shifting.

The mode of operation may be either serial or parallel. In the serial type of operation, digits are handled one at a time in succession. In the parallel system, all digits of a number are handled simultaneously. Although it is slower, the serial system is the more common because it requires much less circuitry. Since the electronic elements used in the arithmetic unit respond to an electrical impulse in less than a millionth of a second, extremely high computing speeds are possible. In the intermediate size computers, several hundred additions can be performed in a second. The large computers operate at the rate of several thousand arithmetic operations per second.

Control Unit

The control unit consists of electronic circuitry the function of which is to interpret program instructions and to direct the operations of the other parts of the computer in accordance with them.

As mentioned previously, in stored-program computers, program instructions in coded form are stored in the memory. In the course of the computation, these instructions are automatically sent to the control unit, one at a time, in proper sequence. Each instruction is stored temporarily in the control unit until it is executed and replaced by the next instruction. This process continues automatically until the entire program has been executed step by step, and the prescribed computations completed.

In externally programmed computers, which will be described further on in the discussion, control is provided through removable wired plugboards, punched cards or punched tape.

Output

The function of the output unit is to take the final results of the computation, and other information desired, from the computer and record them in usable form. The technical term for this operation is "writing." Various writing devices are employed.

In some computers, an electric typewriter connected directly to the computer is used. Information to be recorded is drawn from the memory in the form of electrical pulses in code patterns. The pulses energize electromagnets which in turn actuate the keys of the typewriter. In this process, the pulse patterns are translated into letters and numbers so that the typewritten material is in readable form. Typing is done at the rate of from ten to fifteen characters per second.

To provide higher speeds, line-printers are used, particularly where the volume of output data is substantial. In these machines, an entire line of as many as 130 characters is printed at one time. Speeds as high as 1,500 lines per minute are achieved. The lines of type are set automatically in accordance with the output pulse patterns. The line-printer can be connected directly to the computer in what is termed an "on line" operation or it can be used independently as an "off line" operation. In the latter case, which is the

usual one, the output data is recorded on punched cards, punched paper tape or magnetic tape, which can be used subsequently to actuate the line-printer or a typewriter not connected with the computer to produce a printed record. The data is recorded on cards or paper tape by means of electromagnetically operated punches and on magnetic tape by means of electromagnetic recording heads similar to those used in recording data on a magnetic drum.

Output data is also recorded on cards or tape when it is to be used as input in subsequent computation or processing. Magnetic tape is the fastest medium for output as well as for input, with writing speeds of up to about 50,000 characters per second. In addition, it provides a compact and permanent means of filing data. Also, it can be used over and over again like the tape used in tape recorders. As mentioned under "Input," converters are available by means of which data stored on cards can be transferred to tape. Converters are also available for the reverse process—transferring data from tape to cards.

Cathode-ray tubes are also used as output devices. Characters or traces of an electron beam displayed on the tube are photographed to provide a permanent record. This is a relatively new development which appears to have interesting possibilities for some types of engineering problems.

While there are differences in arrangement, construction, electronic elements and circuitry, the basic functional characteristics are as described. The arithmetic unit, control unit and memory, taken together, are sometimes referred to as the "central processing unit" and are frequently housed in the same cabinet in the small and intermediate size computers. Most computers permit the use of more than one type of input and output device and these usually are separate units.

Operating Procedure

In the operation of the computer, the basic procedure is as follows. The program instructions, on tape or cards, are read by the input unit and stored in the memory. Problem data follows, both constants and values of independent variables. The first instruction is moved from the memory to the control unit where it is stored temporarily, interpreted and executed. The second instruction is moved from the memory to the control unit where it replaces the temporarily stored first instruction. It is then interpreted and executed. This continues until the entire series of instructions constituting the program has been executed and the results of the computation written out through the output unit. If, for example, the problem involved the determination of the sum of two numbers, the first instruction would specify the memory address of the first number and call for it to be moved from the memory to the arithmetic unit. The second instruction would specify the memory address of the second number and call for it to be moved from the memory to the arithmetic unit and there to be added to the number already in the arithmetic unit. The third instruction would call for the sum of the two numbers to be moved from the arithmetic unit to a memory location of specified address. The fourth instruction would call for this sum to be moved from the memory to the output unit to be written out. While this is a very simple example using only four instructions, it serves to illustrate the working process. Many engineering problems require several hundred instructions but the basic process is the same.

Programming

In its broad sense, programming covers everything that has to be done to prepare a problem for solution on the electronic computer. This includes, first of all, defining the problem clearly, deciding upon a method or plan for its solution, and setting up the mathematical equations involved.

Since the computer's mathematical ability is limited to addition, subtraction, multiplication and division, the problem must be resolved into these basic arithmetic operations. If trigonometric functions, square root, integrals or other terms which cannot be handled directly are involved, numerical methods must be used which require only arithmetic operations—finite differences, infinite series, iterative procedures, etc.

Knowing what arithmetic operations have to be performed, the next step is to determine how they may be arranged to best advantage for solution on the particular computer to be used. For this purpose, it is helpful to construct a diagram or flow chart showing the overall procedure to be followed in solving the problem. The chart should show the major segments of computation and the sequence in which they should be undertaken. Consideration must be given at this time to the precision desired, memory requirements, coverage of special cases or alternate conditions, error checks, output format and other pertinent factors.

The next step is the preparation of the program—the detailed step by step procedure for solving the problem. This may take the form of a listing of instructions in word form, in proper sequence, to be followed by the computer in performing the arithmetic operations and logical decisions necessary in developing the solution. Alternatively, it may take the form of a detailed flow chart—an expansion of the overall flow chart previously mentioned, showing each operation and decision and their exact positions in the computational procedure. The chart should not itemize each instruction nor should it specify the manipulation of the parts of the computer itself. It is essentially a detailed pictorial representation of the problem solution logic in connected sequence. A listing of the major mathematical operations to be performed is helpful as a guide in constructing the detailed flow chart. In one form of flow charting, brief procedural statements are shown at the side of the chart correlated with the charted operations.

From the program in word form or in flow chart form, a "coded program" is prepared. This is a detailed listing of machine operations corresponding to the operations listed in the word form program or shown in the flow chart. Each machine operation is expressed in the code used by the computer on which the problem is to be solved. This process, termed "coding" is a tedious task which requires an intimate knowledge of the computer involved. It need not however, require more than a superficial understanding of the problem to be solved or the method of solution. Because coding is so time-consuming and exacting, short cuts have been developed in which the computer itself does much of the detailed work.

The coded program, when completed is a list or tabulation which includes in proper sequence all machine operations in coded form. The terms "coded instruction," "machine instruction" or "program instruction" are used in referring to a coded machine operation.

Before the program can be used, the coded instructions must be recorded on the input medium to be used—punched cards, punched paper tape or magnetic tape. This is done on manually operated card punches, tape punching

typewriters or keyboard operated magnetic tape recording machines. If cards are used, the complete assembly of punched cards, in proper order, is called the "program deck." For either punched paper tape or magnetic tape, the tape on which the coded instructions are recorded is called the "program tape."

The program is now ready to be used except for testing. It is unusual for a coded program to be entirely free from errors when it is first compiled. Errors in logic can be made in the analysis of the problem and in the development of the program. Also, because of the great volume of detail, coding is a common source of error. All errors must, of course, be found and corrected before the coded program can be placed in production. This is done comparing the answers obtained by manual solution of a test problem or problems with the answers produced by the computer. If they differ, a systematic check is made to locate the errors. This is usually done by first checking intermediate results to localize the errors and then checking the suspected segments step by step. The segments can be checked by means of manual controls or through the use of special testing programs in which the computer itself assists in locating the errors. This testing and correcting process is termed "debugging."

After all errors have been corrected, the program is ready for use for all problems of the type for which it was developed. For example, if the program was developed to compute latitudes, departures and error of closure for a survey traverse, it can be used for any survey traverse consistent with limitations which the program may have with respect to number of courses and unknowns. When such a problem is to be solved, the program deck or program tape is taken from the program files and placed in the input unit. The computer is started and the instructions are automatically stored in the memory. The course lengths and bearings, also on cards or tape, are then entered into the computer (or they may be entered manually from a keyboard) and the computation proceeds. Answers are written out by the output unit. The program deck or tape is then returned to the program files where it remains until another traverse is to be computed. Like a phonograph record, it can be used over and over again whenever it is needed.

In the programming operation, the analysis of the problem, the determination of the method of solution, the setting up of the mathematical equations, the construction of the overall flow chart and the preparation of the program either in word form or in detailed flow chart form should be done by an engineer thoroughly familiar with the type of problem involved. This engineer should also know the capabilities and limitations of the computer being used and should have received training in computer programming. He need not know how to operate the machine. Experience has shown that much better results are obtained by providing brief intensive training in computer characteristics and programming procedures for selected engineers than by trying to teach a non-engineer, who may be a computer expert, how to solve engineering problems. The coding part of programming can be done quite satisfactorily by a non-engineer who has been trained for that kind of work. The programming operation up to the coding point requires about 80 to 85 percent of the total preparation time; coding and debugging the program require about 15 to 20 percent.

Subroutines

The programming task may be lightened considerably by the use of "library subroutines" for operations and functions which occur frequently in engineering problems. These are prefabricated standard sequences of computer instructions, complete in themselves, for finding square roots, solving simultaneous equations, calculating trigonometric functions, logarithms, exponential functions, etc. Instead of writing out the detailed computer instructions each time one of these types of operations is encountered, they are written only once and then incorporated into any program as a packaged unit or "subroutine." For any specific problem, the required subroutines are stored in the computer's memory and are automatically called into use in the program as needed by specifying the address of the first step of the subroutine. Provision is also made to return to the main program automatically following the last step of the subroutine.

Automatic Coding

This same device is used in enlisting the aid of the computer itself in developing coded programs. This is done through the use of either "compiling routines" or "interpretive routines." In either case, symbols are used in the initial program which are broader in scope than machine codes and which represent operations familiar to the programmer such as multiply, compare, subtract, divide, etc.

In the compiling process, as each such simplified instruction is read by the input mechanism, it is transformed into the sequence of instructions in machine code necessary to carry out the indicated operation. This is done by means of stored subroutines of coded instructions. The results are assembled and written out on tape or cards as a complete coded program which may then or at some later time be reentered into the computer, stored and executed in the usual way.

In the interpretive process, the symbols or simplified instructions are actually stored in the computer's memory. As each such instruction is reached, it brings into play a sequence of machine coded instructions stored as a subroutine corresponding to the simplified instruction involved. Each simplified instruction is translated and executed as it is reached.

The principal advantages of automatic coding is that it simplifies the programming task and reduces the possibility of errors in coding. However, machine produced programs frequently take longer to run and use more memory space than equivalent programs developed manually.

Programming Example

A simple example will serve to illustrate the conventional programming process. Assume that the equation $(x + y)c = Z$, where x and y are independent variables and c is a constant, is to be solved for several hundred pairs of values of x and y to obtain the corresponding values of Z.

In word form, the instructions to the computer would be the same as would be furnished a person solving the problem manually:

1. Read a pair of values for x and y
2. Add x and y
3. Multiply this sum by c
4. Write the result as Z
5. Return to step 1 and repeat the sequence of instructions with a new pair of values for x and y

This is the program, in word form, for computing any problem of the type $(x + y)c = Z$ such as would be used in computing the area of a trapezoid, the quantity of excavation by the average end area method, etc. The program in flow chart form would be as shown in Figure 2.

In order to solve the problem on an electronic computer, the program must be translated into the code which the computer has been designed to use. Each make and model of computer has its own code. For purposes of illustration, the following fictitious code is assumed.

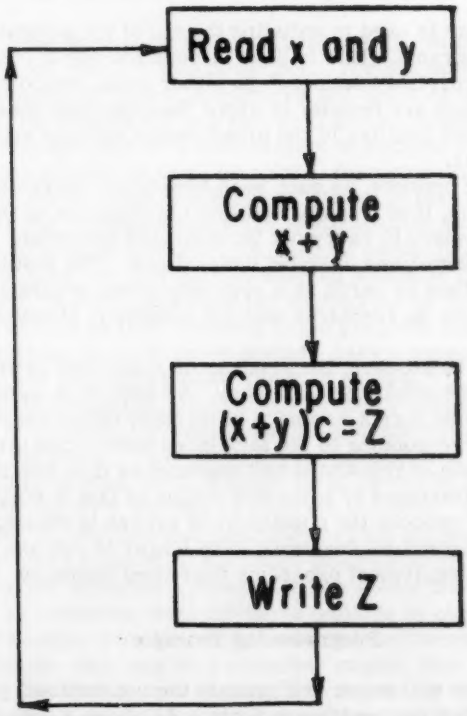


Figure 2

Instruction	Operation Code	Description of Operation
Clear and add	01	The arithmetic unit is set to zero and the number at a specified address in the memory is then placed in the arithmetic unit.
Add	02	The number at a specified address in the memory is added to whatever number is already in the arithmetic unit.
Subtract	03	The number at a specified address in the memory is subtracted from whatever number is already in the arithmetic unit.
Multiply	04	The number at a specified address in the memory is multiplied by whatever number is already in the arithmetic unit.
Divide	05	Whatever number is already in the arithmetic unit is divided by the number at a specified address in the memory.
Store	06	Whatever number is in the arithmetic unit is stored in the memory at a specified address. The previous contents of that memory register are replaced by the new number.
Read	07	Numbers recorded on punched cards, punched tape or magnetic tape are stored in the memory at specified addresses by the input mechanism. The previous contents of the memory registers used are replaced by the new numbers.
Write	08	Numbers at specified addresses in the memory are recorded on punched cards, punched tape, magnetic tape or a printed sheet by the output mechanism. The numbers are not erased from the memory in this process.

The two-digit codes shown in this listing define the operations to be performed. In addition to the operation code, a coded instruction must include the memory address of the number to be operated upon, and in the system illustrated here, the address of the next instruction to be executed. Each of these addresses in this case will have four digits so that the complete coded instruction will have ten digits arranged in this pattern:

Operation Code	Data Address	Instruction Address
xx	xxxx	xxxx

Returning to the example used for illustration, the coded program can now be written. The memory address of each instruction and an alphabetic abbreviation of the operation to be performed are usually listed by the coder with the coded instructions. Memory addresses to be used for values of x, y, c and Z are arbitrarily selected as 0051, 0052, 0053 and 0127 respectively and for the instructions, a block of addresses beginning with 0501. Successive values of x and y, as they are read, will be stored in the same memory locations, 0051 and 0052, each new pair of values replacing the previously stored pair. In the read instruction, only the memory address where the value of x is to be stored need be specified. The companion value of y will automatically be read into the next memory register. Successive values of Z, as they are computed, will be stored in the same memory location, 0127, each new value replacing the previously stored value which by that time will have been written out. The value of the constant c remains unchanged in memory location 0053 and therefore need be read only once. It can be read and stored at the time the program instructions are stored and need not be provided for in the computer instructions for performing the computation.

The coded program then will be:

Coded Instruction					Explanation
0501	RD	07	0051	0502	Read x to 0051, y to 0052
0502	CA	01	0051	0503	Clear and bring x into arithmetic unit
0503	ADD	02	0052	0504	Add y to x
0504	MULT	04	0053	0505	Multiply (x + y) by c
0505	ST	06	0127	0506	Store (x + y)c = Z in 0127
0506	WR	08	0127	0501	Write Z and return to instruction 0501

The first instruction, 07 0051 0502, directs the computer to take the first number (x) punched on the problem data card and store it in memory location 0051, to store in sequence any additional numbers included in the punched problem data in succeeding memory locations, and then to go to memory location 0502 for the next instruction. The second instruction, 01 0051 0503, directs the computer to set the arithmetic unit to zero, then to bring into the arithmetic unit the number stored in memory location 0051, and then to go to memory location 0503 for the next instruction. The third instruction, 02 0052 0504, directs the computer to take the number stored in memory location 0052 to the arithmetic unit and there to add it to the number already in the arithmetic unit and then to go to memory location 0504 for the next instruction. The other coded instructions are interpreted similarly.

The six ten-digit coded instructions are recorded on cards or tape by manual operation of machines designed for that purpose, and are then tested

against a manually computed problem. After whatever errors there might be are found and corrected, the program deck, or program tape if tape is the input medium, is ready to use.

In solving the problem, the program deck or tape is read by the input mechanism which places the coded instructions in memory registers 0501 through 0506. Data cards containing the values of x and y to be used are placed in the input unit, the memory location of the first instruction to be executed, 0501 in this case, is specified by means of manual controls on the computer, and the computer is started. Having been given the location of the first instruction, the computer automatically executes the whole series of instructions for all pairs of values of x and y and writes out corresponding values of Z. This may be done by means of an "on line" typewriter or printer or by punching cards or tape whichever is the output medium used. If the output is in the form of punched cards or tape, these are used to produce a printed sheet on a line printer or tape actuated typewriter.

While this is a very simple case involving only six instructions, it serves to illustrate the programming procedure. A typical engineering problem involves many arithmetic operations and may require a program consisting of several hundred computer instructions covering a complete analysis.

A variety of coding systems are used. In the example given here, a two-address system was used. Each coded instruction contained two addresses, one for the number to be operated upon and another for the next instruction to be executed. Single-address, three-address and four-address systems are also used. In the single address system, only the address of the operand is given. Instructions are executed in numerical sequence unless otherwise specified so that it is not necessary to furnish the address of the next instruction. Some two-address systems also use this device, the two addresses being used for the two operands involved in the operation. In the three-address system, two addresses are used for operands and the third to specify where in the memory the result of the operation is to be stored. The four-address system uses two addresses for operands, one for storing the result of the operation and the fourth for the location of the next instruction to be executed.

Logical Decisions

The way in which the computer can make logical decisions can be illustrated by its use in computing highway profile grades. The computation of grade elevations at successive stations on tangents is a simple incrementing process. On any one tangent, the grade elevation at a station is a constant distance above or below the grade elevation of the previous station. On vertical curves however, the grade elevation at a station is determined by adding to or subtracting from the tangent grade elevation, the vertical distance by which the vertical curve deviates from the tangent at that point. Thus in computing profile grade elevations, there are two sequences of operations involved—one for points on tangents and an additional sequence for points on vertical curves. The overall flow chart could be drawn as shown in Figure 3.

In the detailed program, the test to determine if the station lies on a vertical curve would be made by comparing the station with the stored station of the P.V.C. If it is equal or smaller, the computer has not yet reached the vertical curve and the station is on the back tangent. If it is larger, a second test is necessary to determine if the station is less than or greater than the

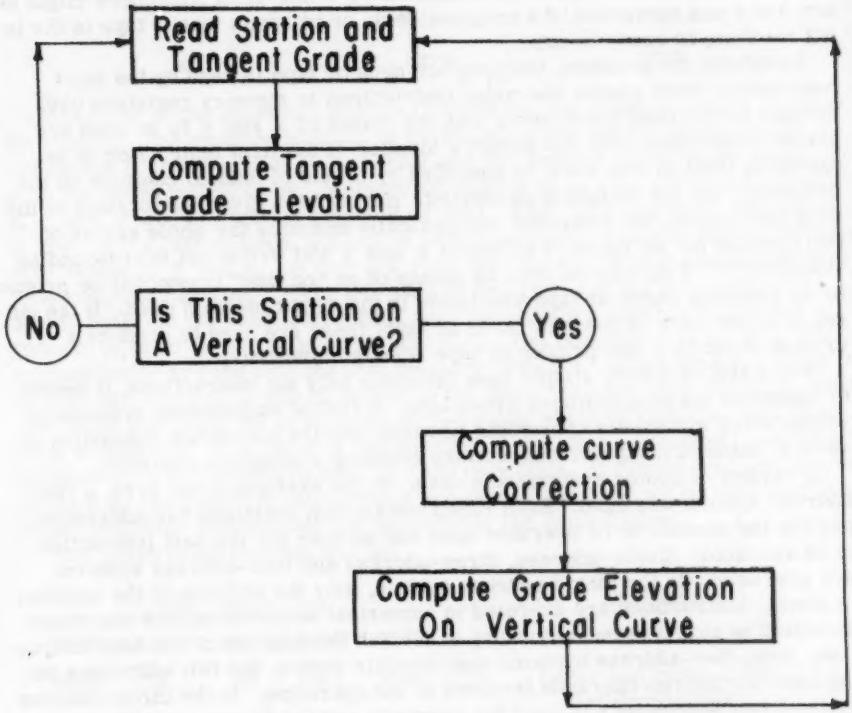


Figure 3

station of the P.V.T. If it is equal or less, the station is on the vertical curve and if greater, it is on the forward tangent. This is an abbreviated description of the process but serves to explain how the computer can determine which of two courses of action to follow. By this means, the computer can compute grade elevations for an entire project proceeding along a succession of tangents and vertical curves in a continuous operation.

Number System

In this discussion, frequent mention has been made of the representation of numbers by code patterns of the presence and absence of holes or magnetized spots or of positively or negatively magnetized cores. This method of coding is based on the binary number system in which there are only two symbols, 0 and 1, in contrast to the decimal number system in which there are ten symbols, 0 to 9. In the binary system there are no digits larger than 1, just as in the decimal system there are no digits larger than 9. Since only two kinds of digits are used, binary numbers may be represented by the

presence and absence of holes in a card or paper tape, the presence and absence of magnetized spots on magnetic tape or magnetic drums, the presence and absence of electrical pulses in a circuit, the "on" or "off" condition of an electronic switch, the conducting or non-conducting state of an electron tube, etc.

The binary digit 1 may be represented by one of two such mutually exclusive conditions and the binary digit 0 by the opposite condition. Thus any number in the binary system can be represented by a pattern of holes and no holes, magnetized spots and nonmagnetized spots and other similar devices representing a corresponding combinations of ones and zeros. Similarly, a number can be transferred from one part of the computer to another by transmitting through the electronic circuitry a pattern of electrical pulses and intervals between pulses corresponding to the combination of ones and zeros which represent the number.

In the binary system, a number is represented in terms of successive powers of 2 just as in the decimal system a number is represented in terms of successive powers of 10. For example, the number 302 in the decimal system can be written as:

$$3(10^2) + 0(10^1) + 2(10^0)$$

In the binary system, the same number would be expressed as 100101110 which means,

$$1(2^8) + 0(2^7) + 0(2^6) + 1(2^5) + 0(2^4) + 1(2^3) + 1(2^2) + 1(2^1) + 0(2^0)$$

or in the more familiar decimal equivalents,

$$256 + 0 + 0 + 32 + 0 + 8 + 4 + 2 + 0 = 302$$

From this it can be seen that in either the decimal or binary system, the digits used to form a number actually represent the coefficients of successive powers of the base or radix of the system, with the coefficient of the zero power in the units position. The binary equivalents of the decimal numbers zero to nine are as follows:

Decimal	Binary	
0	0	$0(2^0)$
1	1	$1(2^0)$
2	10	$1(2^1) + 0(2^0)$
3	11	$1(2^1) + 1(2^0)$
4	100	$1(2^2) + 0(2^1) + 0(2^0)$
5	101	$1(2^2) + 0(2^1) + 1(2^0)$
6	110	$1(2^2) + 1(2^1) + 0(2^0)$
7	111	$1(2^2) + 1(2^1) + 1(2^0)$
8	1000	$1(2^3) + 0(2^2) + 0(2^1) + 0(2^0)$
9	1010	$1(2^3) + 0(2^2) + 1(2^1) + 0(2^0)$

This table can of course be extended to show the binary equivalent of any decimal number. For example, the binary equivalent of the decimal number 3201 is 110010000001 where the 1 at the extreme left is the coefficient of the eleventh power of 2.

Since the conversion of decimal numbers to binary numbers and vice versa is awkward, it is handled either through programming subroutines or automatically by electronic circuitry in the computer. It is not necessary for the user of the computer to convert decimal numbers to the binary system—numbers are entered in the computer in decimal form. Also answers are produced in decimal form. To simplify the internal conversion process, the binary coded decimal system is used in many computers. In this system, each decimal digit is represented individually by a group of binary digits. Various equivalents are used, perhaps the most common of which corresponds to the straight binary system described above using four binary digits to represent each decimal digit. Thus the decimal number 3201, which in the straight binary system was shown above to be 110010000001, would be 0011001000000001 in the usual binary coded decimal form. The four digits 0001 at the extreme right represent the decimal digit 1, the next four digits proceeding to the left represent the 0, the next four, the 2, and the four at the extreme left, the 3 so that taken together they represent 3201. In the computer, the arithmetic and control circuits operate on groups of four binary digits, called "bits," each group representing a decimal digit. The patterns of magnetized spots on tape or drums, of magnetized cores and of electrostatic charges, previously described under COMPONENTS, are arranged in this same way. This method of representation is called the 8-4-2-1 system. Similar systems are in use termed the 2-4-2-1, the "excess-three," "two out of five" and others. Each system has certain advantageous characteristics and detailed information can be found in the reference material listed at the end of this discussion. The reference material also provides information on the addition, subtraction, multiplication and division of binary numbers. These processes are similar to those used with decimal numbers but somewhat simpler.

Externally Programmed Computers

This discussion has been directed principally toward electronic computers in which the sequence of operations is controlled by a program of computer instructions stored in the computer's memory. Computers of this kind are called "stored program" or "internally programmed" computers.

The earlier automatic digital computers beginning with the mechanical Analytical Engine conceived by the British mathematician Charles Babbage in 1833 and extending to the ENIAC which was placed in operation in January 1947 all used some external means for controlling the sequence of operations—punched cards, punched paper tape or wired control panels. The memory was used only for storing problem data. These machines are called externally programmed computers.

The EDVAC (Electronic Discrete Variable Automatic Computer), placed in operation in 1949, is believed to be the first stored program computer, at least in this country. Since then, all of the large and intermediate size computers, as well as most of the small computers, provide for this type of sequence control.

There are however, a number of small computers which are externally programmed. The most common sequence control device is a wired control panel or plugboard. The wires are connected to metal hubs by plugs or pins which extend through the board and press against contacts in the machine. The ways in which the wires are connected determine the operations to be performed and their sequence. The plugboards are removable and in normal usage there will be many of them kept in a wired, ready to use condition—one or more for each type of problem which recurs frequently.

Punched cards are used for entering problem data. A card is read, a group of arithmetic operations is performed on the problem data read from the card, and the answers are punched in the same card. In most cases, as answers are punched in one card, problem data are read from the next card. The computation is completed in the time between reading successive cards. Where many program steps are required in the solution of a problem, two or more passes of cards through the computer are required, each pass using a different plugboard. While minor variations in the sequence of operations are possible through wiring arrangements, this type of computer is much less flexible than the stored program type. The memory is quite small and because of the multiple card passes and the need for changing plugboards, overall operating speeds are relatively slow.

In another type of externally programmed computer, the sequence of operations is controlled by punched cards on which program instructions are recorded. General-purpose control panels wired to perform a number of basic operations are used in conjunction with the cards. As the cards are read, the appropriate arithmetic operations are selected by the punched instructions and executed. Problem data to be operated upon is punched into the same cards which contain the instructions. The specified operation is performed as the card is read—instructions are not stored in the memory. Results of the computation may be stored temporarily, punched into cards or printed in report form by means of an on-line printer. Since the wired control panels are general purpose panels, to change from one problem to another it is necessary to change only the program deck. In an alternative method of operation, special purpose panels, arranged specifically for the problem to be solved are used. This reduces running time for a given problem but requires wiring new panels for each new problem. In either case, since instructions are read from cards and executed as read, the speed of operation is limited to the rate at which cards can be read. Variations in the sequence of operations can be made by selective reading of instruction card columns.

A third type of externally programmed computer is similar to the plugboard computer first described except that sequence control is accomplished by inserting pins in a prewired board. The pattern or arrangement of the pins governs the operations to be performed and their sequence. Data is entered either from a keyboard or by means of punched paper tape. A small magnetic drum memory is provided for problem data. Results are printed out on a typewriter type of printer.

In still another type of externally programmed computer, program instructions are entered from a keyboard the first time the problem is solved. As this is done, a punched program tape is produced which may then be used as the control for automatically repeating the solution with additional sets of given data. Problem data is entered either manually from the keyboard or by means of punched paper input tape and stored in a small magnetic drum

memory. Intermediate results are also stored in the memory. Final results of the computation, and intermediate results if desired, may be typed in report form by an on-line typewriter, punched in paper tape, or both. Wired control panels are provided as supplementary sequence control, primarily for subroutines and logical decisions.

While the externally programmed computers are not as fast or as flexible as the internally programmed computers, their programming is simpler. They can be employed for the solution of any problem which can be resolved into basic arithmetic operations and are widely used for both accounting and engineering calculations.

Applications

As a rough guide, the number of hours required to develop a typical computer program, beginning with the analysis of the problem and extending through the compilation and debugging of the coded program, is about equal to the number of computer instructions involved. The use of the procedures described under AUTOMATIC CODING can shorten this time substantially but even then, the complete programming operations for a problem solution requiring several hundred computer instructions might still extend over a period of several weeks. When the program is completed and placed in use however, the actual computer time for solving such a problem for one set of given values would be only a few minutes, or in the large computers, a few seconds.

Because the preparation of the program is so time consuming and costly, it is obviously uneconomical to use the computer for a "one time" type of problem, unless of course, the program could be prepared in less time than it would take to solve the problem manually. The computer is of greatest advantage in the case of frequently recurring problems where program development costs can be spread over many applications and where, except in the first instance, the program is immediately available for use. Most highway and bridge problems are recurrent and tremendous savings in time and manpower are attainable by using an electronic computer for their solutions.

In earthwork computation, for example, about 80 to 90 man-hours per mile are required using the conventional method of plotting, checking and inking cross sections, spotting grade profile elevations, drawing roadway templates, planimetering areas and computing volumes and mass diagram ordinates. In the electronic computer method, volumes and mass diagram ordinates can be produced at a rate of 2-1/2 to 3 hours per mile using an intermediate size computer, including the punching of terrain and template input data on cards or tape. Only about 15 minutes of computer time is required. Also, because the computer results are obtained entirely by arithmetic computation, errors and inaccuracies in plotting, planimetering and transcribing data are completely eliminated. The computer method does not produce drawn cross sections. If they are necessary at critical points, they can be produced rapidly and accurately by an electronic plotter actuated by the computer input cards or tape or they can be plotted manually.

In other types of problems, even more impressive savings are attained. The computation of the dimensions and elevations needed for laying out, fabricating and constructing multispan curved bridges with variously skewed piers and abutments is tedious and time consuming. In one project of this kind with fourteen spans, a complete solution was obtained on an intermediate

size electronic computer in 11 minutes. Based on similar problems done previously, it was estimated that it would have taken 22 man-days to solve the problem using a desk calculator.

These two examples are typical of the savings in time and manpower which are possible. Even more important however, are the savings in construction costs and highway user costs resulting from the more exhaustive analyses and more refined designs made possible by high-speed automatic computation. Using an electronic computer, the investigation of several alternate designs can be completed in less time than it would take to make one investigation by other means.

Other computer programs in the highway and bridge engineering fields cover a wide range of applications including highway planning, location and design, soils mechanics, structural analysis and design, traffic analysis, surveying computations, quantity computations, bid analysis and cost control. Still other programs are in process of formulation.

The heavy burden of program development has been eased substantially through cooperative effort. Users of the same makes of computers have formed user groups which meet periodically to review progress made and plans for further development. Programs developed by one member of a group are made available to other members. Through such program exchange, duplication is minimized and maximum progress is assured within the user group.

Because each computer uses a different machine language or code, program exchange between users of different computers is more difficult. For this purpose, a library of electronic computer programs has been established within the Bureau of Public Roads to serve as a central point for the receipt and distribution of computer programs developed for use in the highway and bridge fields. Programs are contributed by the highway departments, consulting firms, educational institutions, computer manufacturers and others. Each program received is adjusted to remove terminology peculiar to the computer for which it was developed. The final library version of the program is expressed solely in English and mathematical terms in accordance with an established format to assure uniformity of content and complete coverage. It includes a detailed flow chart and is otherwise sufficiently complete and detailed for ready coding for use with any make of digital computer. In addition, library programs are developed within the Bureau of Public Roads both directly and through cooperative projects with State highway departments and educational institutions or research organizations. Users are kept informed of the programs available from the library through program listings which are issued periodically.

The Future

The general tendency in developing computer programs for highway and bridge work has been to follow exactly the procedure used in solving the problem with pencil and paper or a desk calculator. This is one reason that such rapid progress has been made in converting to electronic computation. However, because the computer performs mathematical operations so rapidly, there is much greater latitude in the selection of methods. Assumptions, approximations and rule-of-thumb procedures usually made in analysis and design can be discarded and entirely new approaches based on fundamental

principles can be used. In this way, proper consideration can be given to all significant variables and conditions involved in the problem to obtain more refined designs than previously were considered to be economically feasible. There is much room for research and development in this area. In comparison with the potentialities of the electronic computer, applications in the highway engineering field to date, although seemingly extensive, have actually been quite limited.

With respect to the computer itself, the present rate of research and development assures continued improvement in operating characteristics. The development of faster memory devices is moving forward rapidly. The trend toward a greater use of transistors is producing substantial reductions in space and power requirements. New materials and devices are being investigated in an effort to develop faster arithmetic units, more flexible input devices and greater reliability.

Even more important to the user, however, is the work that is being done to make the computer easier to use. A great deal of work is being done in the area of automatic coding which was described briefly in this discussion. The objective is to develop a system in which the computer will produce a solution from instructions expressed in the natural language of the user, that is, in a combination of words and mathematical terms. In this way, the engineer will be able to use the computer without working through a coder, and of course, the time required to prepare a problem for computer solution will be reduced materially.

CONCLUSION

This discussion is essentially an introduction to the electronic computer and its use in highway and bridge engineering. No attempt has been made to provide an exhaustive treatise on the electronic computer. Discussions of flow charting and coding techniques, instruction modification, scaling, error checking, relative programming and other techniques and devices have purposely been omitted. Also, no attempt has been made to discuss electronic circuits or numerical analysis. Information on these and other items which may be of interest to those who wish to pursue the subject further are given in the reference material listed at the end of the discussion.

The electronic computer is a powerful tool for the engineer and will become even more powerful in the future. It is important to bear in mind however, that it is only a calculating machine. The thinking involved in the solution of an engineering problem must continue to be done by the engineer. Although the computer can call upon its memory for information and can make simple logical decisions, it can do these things only when explicitly directed to do them by means of instructions in the program. It will do exactly what it is directed to do—no more and no less.

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QUALITY CONTROL FOR LARGE HIGHWAY PROJECTS[a]

Closure by Edward A. Abdun-Nur

EDWARD A. ABDUN-NUR,[1] F. ASCE.—The purpose of this paper was to outline an approach that adapts industrial quality control procedures to the civil engineering field, with ensuing reduction in costs and improvement in quality. These advantages have resulted when quality control was introduced in an uncontrolled operation in industry. The aim was to stress the idea that quality control starts with the first concept of the project, and ends only when the facility is completed and ready to operate. This, as contrasted with the more commonly accepted use of "Quality Control" as being the control of materials only—the most prevalent procedure in construction work.

Because the paper tries to outline an approach, it had perforce to include generalizations which were intended only as guides or examples of what has been done, leaving the more detailed developments in each application to the engineers faced with the specific problems.

Mr. Davis has called attention to a very important point related to the uniformity of density in a compacted layer. The author agrees that such lack of uniformity must be watched for very carefully, and operations adjusted in such a manner that a practical uniformity is attained. The suggestion made in the paper for increasing the thickness of compacted layers in granular materials has resulted, in most instances, in the use of vibratory equipment which has given surprisingly uniform densities throughout the thickness of the layers. As long as the equipment is powerful enough to permit vibration to penetrate the full thickness of the layer, and perhaps a little more, then compaction seems to take place adequately at the bottom of the layer as well as at the top. Occasionally, situations develop which result in what Mr. Davis feared, and one must watch for such conditions, and take corrective measures if this happens.

It is gratifying to note that Mr. Davis' experience shows that there are advantages to opening training meetings to contractors' key personnel.

The comments of Mr. Tuthill regarding the use of end-product provisions are well taken. Here again, the engineer has to decide whether the use of end-product provisions in any given instance would have the advantages mentioned in the paper, or whether it might lead to trouble. The author knows of instances where such provisions have given trouble, and other instances where they have worked out to the advantage of the owner, the contractor, and the engineers. That is why it is most important that specifications be tailored to each individual situation and not simply copied, inasmuch as what served the purpose in one case, may be completely out of line in another case.

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a. Proc. Paper 1626, May, 1958, by Edward A. Abdun-Nur.

1. Cons. Engr., Denver, Colo.

Mr. Dempsey has raised several interesting points that bear comment. His concern about running up prices, due to lump-sum items, fails to take into consideration that the theory of competitive bidding is based on the assumption that competition will keep the mark-up to a minimum consistent with doing the work realistically. This mechanism works for lump-sum items in the same manner as for other items. In fact, every item on a bid schedule "lumps" equipment, labor, materials, and usually several operations. The author believes that with increasing accuracy in the preparation of estimates, the more ready availability of electronic computers, and with improved surveying methods, lump-sum items in the future will in many cases involve less risk than the accepted standard bid items have in the past.

The question of finish screening has come in for a lot of discussion. Much of it has been on "general principle", because it is a new idea in many operations. Actually in most instances, if full advantage of it is taken, very few operators can afford to be without it, as it would save them money. In a few instances, it would break even with existing costs, and in a few other instances, the cost increase would amount to 1 or 2 cents per ton of aggregate, an amount that would be lost in the final cost of concrete, when the cost of the aggregate is as small a fraction of the cost of the finished concrete as it is today. On the other side of the ledger is the improved uniformity, and therefore improved quality, that will increase the factor of safety and in the long run permit savings through reduced design requirements.

Mr. Dempsey cites the hot weather concrete problems in the Lake Maracaibo area as a reason for accepting concrete placement at a high temperature. Whereas the author agrees with Mr. Dempsey that retarding agents do help hot weather concreting problems, it is nevertheless a fact, repeatedly confirmed by the findings of research, that concrete placed at high temperature does not have the inherent quality that the same mixture placed at a lower temperature would have. It becomes then a question of economics, whether the improved quality is worth the extra expense of taking the measures required to cool the concrete mixture before placing it in the forms. This is a matter of engineering judgment that has to be left to each engineer to evaluate for each specific set of circumstances.

Automation is the order of the day. It has been brought about by many developments and changes in our social order, and it is the writer's belief that it will increase at an accelerated rate. It tends to accomplish the task without fatigue, in a more reliable manner, and at a cheaper cost than labor can offer. What may have appeared to "have the distant appeal of expensive luxury" to many yesterday, is fast becoming a necessity today, and will increasingly be so tomorrow.

In the final analysis, no matter how well prepared designs and specifications are, their common sense application must be left to the engineer on the job. There will always be those who will come up with the answer given in Mr. Dempsey's example regarding the sprinkling of the sub-grade, but the writer has more confidence in the judgment of those charged with construction than to believe that such interpretations would be the general rule. Meanwhile, the contractor would be bidding on definite requirements in contrast to bidding on the whims of an unknown engineer when he has to bid on "as determined by the Engineer". If he is forced to water the sub-grade unnecessarily after a rain, he has already allowed for that in his bid, and it will hurt only his feelings and not his pocket book.

The writer is gratified to learn that Mr. Dempsey feels that smaller construction projects can benefit from the application of the approaches outlined in this paper. This has been the repeated experience of the writer.

The comments of Messrs. Davis, Tuthill, and Dempsey are appreciated and have served to strengthen the paper and enhance the particular facets touched upon.

In closing, the writer wishes to stress again the importance of follow-up through all stages of the work, in order to attain the important essentials included by the engineer in the designs and specifications.

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TESTS OF CONCRETE PAVEMENTS ON GRAVEL SUBBASES[a]

Discussion by Bengt F. Friberg

BENGT F. FRIBERG.[1]—The careful and admirably reported load tests of 8-in. concrete pavements on open-textured gravel subbases, as well as previously reported tests in the same program of 6-in. slabs on dense-graded sand and gravel subbases (1) by the same authors, are a welcome and valuable addition to the few documented load tests on concrete pavements listed in the bibliography. The tests are believed to be the first to include different subgrades and subbases as a designed variable with other conditions identical. Aside from the expressed purpose of the test program to study structural effects of various subbases, the greater value of the research lies in the various observations of subgrade properties, and in the study of theoretical pavement deflection and stress formulas in relation to observed values under carefully controlled experimental conditions.

The paper lists theoretical formulas for maximum stress and maximum deflection which have been developed by H. M. Westergaard from 1926 to 1947, and modifications of them. As included in the stress formulas, concrete modulus of elasticity E and subgrade modulus k occur mainly in the expression for the radius of relative stiffness L, with very small variable influence proportionate to the fourth root of E/k. In the deflection formulas variations in the subgrade modulus have greater effect, with influence generally inversely proportionate to kL^2. Accordingly, maximum stresses are very insensitive to the modulus of elasticity as well as to subgrade modulus. Theoretical deflections, on the other hand, are very nearly inverse proportionate to the subgrade modulus. Stresses derived from strains are directly related to the modulus of elasticity. Good agreement can be obtained between experimental and theoretical deflections by appropriate choice of subgrade modulus in the theoretical formulas, and between experimental strains and theoretical stresses by appropriate choice of modulus of elasticity applied to the experimental strains.

The possible choice of subgrade modulus is wide, as indicated in Fig. 4 for various sizes of bearing plates, as well as in Fig. 20 showing directly measured relations between deflections and pressures under the slab. The authors have selected values of subgrade modulus indicated for 30-in. diameter bearing plates in Fig. 4 at 0.050-in. deflection. However, Fig. 20 indicates values of subgrade modulus for representative deflections, which are much higher than the values obtained from 30-in. bearing plates. The differences are well illustrated by Table 5. No great significance can be attached to agreement—or non-agreement— between the various deflection formulas and

a. Proc. Paper 1800, October, 1958, by L. D. Childs and J. W. Kaperwick.
1. Cons. Engr., St. Louis, Mo.

experimentally observed deflections under such conditions. The essential relationship, that the total pressure exerted within the deflection cone must equal the imposed load, cannot be deduced from the theoretical formulas listed. Considering the sensitive relationship between subgrade modulus and slab deflection this theoretical deficiency is regrettable.

Comparisons between theoretical stresses and experimental strains appear to be somewhat more certain, because the modulus of elasticity is subject to more objective determination. The authors selected a value of 4,500,000 psi. compared to average dynamic E values of 4.5 and 5.2 million psi. at 7 and 28 days respectively. The theoretical stress formulas contain no procedure for independent appraisal of stresses from reaction and load distribution.

The above comments illustrate deficiencies in the existing listed stress and deflection formulas. In the complicated forms, derived from rigorous mathematical models with approximations introduced for the sake of solution, the formulas lack internal direct controls of visualization and judgment. The elastic behaviour of a slab, as expressed in stresses and deflections resulting from concrete strains caused by the stresses, is entirely determined by the imprint, and orientation of the wheel loads, and by the distribution pressures from the soil against the slab. Stress and deflection determinations which do not permit relatively easy checking of loads with reactions, and of moments and stresses lack essential needs for design judgment. The deficiency is illustrated by various adjustments in the theoretical formulas over a 20-year period.

The difficulties mentioned above have been overcome in the successive approximation method "Sector Analysis for Concrete Pavement Load Stresses".[2] Sector Analysis principles and assumptions are summarized as follows:

1. The pavement is considered as a number of independent elemental wedge shaped elements with their common apex at the most convenient load center, extending radially an unlimited distance, or to an edge of the slab. The load is distributed in relation to apex angle of the sectors and the principal elemental design sectors are assumed narrow so that plane sections can be applied.
2. The portion of the wheel load acting on each wedge element is in equilibrium with the total subgrade pressure under the element, and the wheel load is assumed distributed on the wedge elements in the principal directions in such proportion that their apex deflections are equal. (An approximate adjustment for shears on radial planes.)
3. For each wedge element the load above, the placement of which is taken equal to the radial coverage of the wheel imprint, called the tire load sector, is in equilibrium with the subgrade pressure below within a circumferential section of zero shear, called the reaction sector. Numerical values of the reaction sector radius can be determined through successive approximations for any size wheel imprint, pavement dimensions, and subgrade properties, as outlined and given for conventional cases by approximate values in the paper.[2] The reaction sector radius is independent of the magnitude of the load.
4. For each known reaction sector radius and soil pressure distribution within the reaction sector, deflections along the sector and moments

2. ASCE, Proceedings Paper 1153, January 1957, by Bengt F. Friberg.

and stresses on any elemental section can be computed directly for known values of tireload sectors.

5. The reaction sector radius is influenced by restraints, without which the load could not be distributed over a larger area. A negative maximum moment (tension at top) exists at the circumferential section of zero shear, defined by the reaction sector radius, which moment is balanced by more distant slab lifts or wheel loads as external restraints on the reaction sector elements. For sectors which are restrained at the apex, (such as the elemental sectors radiating from an interior load, or along the edge for an edge load), the restraint stress at the apex is determined as that for an upwardly directed concentrated load at the apex, p_r (with restraint stress 6 p_r/h^2), so proportioned in relation to stresses caused by the wheel load and its subgrade reaction without restraint, that the corresponding positive and negative moment stress areas meet geometric requirements of tangential slopes or equilibrium conditions.

The manner in which the Sector Analysis principles and assumptions are applied to actual pavement wheel loads is described in the reference (2). The practical value of the design method is that deflection diagrams are automatically a part of the analysis, uncorrelated assumptions of subgrade modulus are avoided, and the distribution of wheel loads can be compared with actual pavement dimensions.

Some of the interior load tests by the authors could not agree with rigorous interior load stress formulas because the reaction sectors come too close to the edge of the pavement for appreciable external restraint moments to be active; accordingly, the negative moment at the reaction sector circumference must be near zero, and the apex restraint must be correspondingly greater than that for true internal load conditions. In Table A are given the reaction sector radii for various restraint conditions in the 8-in. slabs under 12-in. diameter tire imprints, for 100, 200, and 400 psi. subgrade modulus. The test slabs measured 144 by 216 inches. Not less than 144 in. dimension was available from corners, adequate for external restraint of the corner sectors with probable maximum reaction radius between 70 and 80 inches. Only 108 inches of slab dimension was available longitudinally from center and edge loads however, which is not much more than the probable reaction sector radius between 80 and 100 inches, and insufficient for any appreciable external restraint. Only 72 in. dimension was present for transverse sector elements on each side of a center load, much too short for any exterior restraint, and, as indicated in Table A for Short Sectors, approximately the dimension to zero slab deflection without exterior restraint if the subgrade modulus were slightly over 200 pci. and so short that some downward deflection at the transverse edge would be noticeable if the subgrade modulus were 100 pci.

The above data show that only corner loads and deflections could be expected to correspond closely with assumed design conditions. For central loads, deflections would be greater than theoretical because of the deficiency in transverse reaction sector radius, and a greater portion of the load would be carried by longitudinal than transverse sectors. The longitudinal stress at the load would be higher than theoretical because most of the load would be distributed in longitudinal direction, and it would be further increased because of absence of negative exterior moments. The transverse stress would be correspondingly lower than theoretical. The theoretical stress formulas are

TABLE A. SECTOR ANALYSIS VALUES OF REACTION SECTORS FOR 12 INCH CIRCULAR TIRE IMPRINT, PER REFERENCE (b).

	Tire Sector Radius in.	Reaction Sector radius for Subgrade modulus of:		
		100 pci.	200 pci.	400 pci.
Reaction Sector Radius for Corner Load (No apex restraint)				
Diagonal element	12.7	73"	62"	53"
Edge element	~10	72"	61"	52"
Reaction Sector Radius for Interior Load (Apex and Exterior Restraint)				
All elements	6	100"	84"	70"
Reaction Sector Radii for Edge Load (Edge elements both apex and exterior restraints; Transverse element no apex restraint)				
Edge elements	6	100"	84"	70"
Transverse element	12	73"	62"	53"
Short Sector (No external restraint, zero deflection at reaction sector radius.)				
Zero deflection radius	6	91"	76"	63"

inadequate for these general slab dimensions; however, the approximate conditions can be appraised with Sector Analysis.

In Table B the approximate values of variables for appraisal of the tests by Sector Analysis are given. The variables are obtained from data in reference (2) for 100, 200, and 400 pci. subgrade modulus; appropriate figures or equations in the reference are indicated. The longitudinal reaction sector radii are intermediate values between those for full and no exterior restraints as are the stress coefficients. Deflections and stresses are computed for a 10,000-lb. load.

In Fig. A, curves of deflection at corner-, edge-, and center-loading are shown as obtained from Table B, for different values of subgrade modulus. Experimental deflection values from the different tests are shown as well. The values of subgrade modulus which correspond to the measured deflections for the different load positions are given below:

For:	Corner Load	Edge Load	Center Load
Clay subgrade	150 pci.	100 pci.	150 pci.
5-in. subbase	190 "	110 "	170 "
10-in. "	230 "	120 "	190 "
15-in. "	250 "	130 "	200 "

TABLE B. SECTOR ANALYSIS OF 8-IN. SLAB FOR 10,000-LB. LOAD AND 100, 200 and 400 PCI. SUBGRADE MODULUS. SLAB DIMENSION 144 BY 216 INCHES.

Item	Ref.(b) Fig. Eq.	Unit	Subgrade Modulus, pci. 100	200	400
CORNER LOAD, 6400 lb./rad.					
Reaction Sector Radius					
Diagonal t = 12.7"	Fig. 8	c, in.	73	62	53
Edge t ~ 10 "	Fig. 8	c, in.	72	61	52
Diagonal element load, p	Eq.(3)	#/rad.	6450	6500	6500
Deflection (n = 3)	Eq.(7)	in.	.072	.050	.035
Tire load sector, diag.		t/c	.174	.205	.24
Stress coefficient	Fig. 8	m	3.2	3.0	2.7
Stress	mp/h^2	psi	323	305	275
Strain, ($E = 45 \cdot 10^6$)		10^{-6}	72	67	61
CENTER LOAD, 1600 lb./rad. t = 6 in.					
Reaction Sector Radius					
Longitudinal, i	Figs {10 11	i/b_o in.	97	83	70
Transverse, w		in.	72	72	64
Deflection cone constant					
Longitudinal n_ℓ			3.0	2.8	2.5
Transverse n_t			2.7	2.8	2.9
Load distribution					
Longitudinal element	Eq.(3)	#/rad.	2000	1850	1850
Transverse element	Eq.(4)	#/rad.	1200	1350	1350
Deflection	Eq.(7)	in.	.013	.0075	.0047
Stress coefficient					
Longitudinal element	Figs {10 11	m_ℓ	5.3	5.0	4.7
Transverse element	"	m_t	5.4	5.2	5.0
Stress					
Longitudinal	$\frac{mp}{h^2}$	psi	-165	-145	-135
Transverse	$\frac{mp}{h^2}$	psi	-100	-110	-105
Longitudinal strain	$\mu = .15$	10^{-6}	34	29	26
LONGITUDINAL EDGE LOAD, 3200 lb./rad. t_ℓ = 6 in. t_t = 12. in.					
Reaction Sector Radius					
Longitudinal i		in.	97	83	70
Transverse c	Fig. 8	in.	73	62	53
Deflection cone constant					
Longitudinal			2.9	2.7	2.5
Transverse			3.0	3.0	3.0
Load distribution					
Longitudinal	Eq.(5)	#/rad.	3750	3800	3850
Transverse	Eq.(6)	#/rad.	2100	2000	1900
Deflection	Eq.(7)	in.	.023	.015	.010
Stress coefficient					
Longitudinal	Figs {10 11	m_ℓ	5.3	5.0	4.7
Stress	$\frac{mp}{h^2}$	psi	310	295	285
Strain		10^{-6}	69	66	63

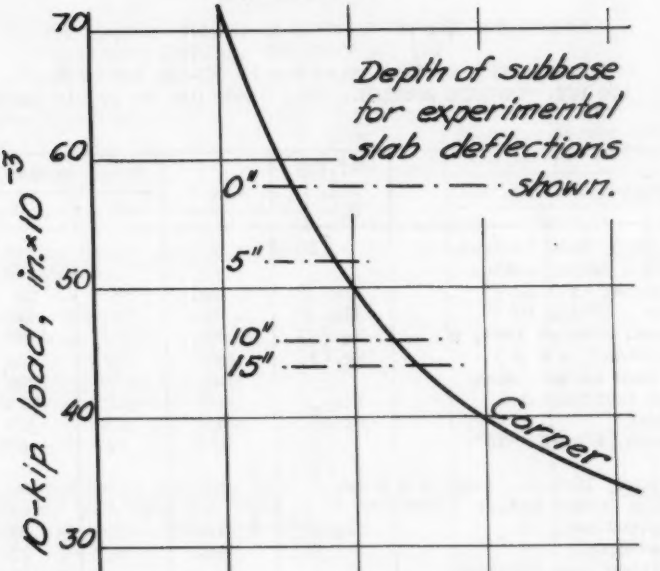

Fig. A.—Deflections at Corner-, Edge-, or Center-Load, by Sector Analysis for 100- to 400-pci. Subgrade Modulus, and Observed Deflections on 12- by 18-ft. Slab.

The values are between those indicated by the 30-in. plate and the pressure cells. The values of stresses and strains, corresponding to the above subgrade moduli can be interpolated from the data in Table B.

Below are given the comparative Sector-Analysis (S.A.), and experimentally observed strains from Fig. 24, in millionths in./in. for 4,500,000 pci. modulus of elasticity, and Poisson's ratio of 0.15 applied to longitudinal center load strain:

	Load Position					
	Corner		Edge		Center	
	S.A.	Exp.	S.A.	Exp.	S.A.	Exp.
Clay	69	76	69	93	31	49
5-in. Subbase	67	74	69	90	30	41
10-in. "	66	67	68	87	29	46
15-in. "	65	63	68	85	29	44

The comparison between the Sector-Analysis and experimental strains is good for corner loads, but no better than obtained with some of the theoretical formulas for edge and central loads. Nevertheless, the reasons for the discrepancies can be suggested from considerations illustrated with Sector Analysis. The low values of subgrade modulus for edge loading suggested by the observed deflections would indicate imperfect subgrade support at the edge under the experimental slabs. The comparison in Fig. 24 supports this suggestion; there was very little difference in edge deflection between flat and curled slabs, but in the curled slabs edge load strains were substantially lower, and in better agreement with Sector-Analysis strains. For interior load neither deflections nor strains changed appreciably from flat to curled slab conditions; however, any lack of edge support would cause even greater portion of the center load, than the 2,000 to 1,800 lb./radian indicated in Table B, to be distributed in longitudinal direction, and the longitudinal strain would then be correspondingly greater. The experimental transverse strains might give a clue to the approximate distribution in longitudinal and transverse direction.

When comparing strains with stresses it must be remembered that restraint stresses probably always are present away from corners in addition to the load stress. Warping restraint stresses with tension strains near the surface probably were present which were relieved incident to the slab curvatures occurring under center and edge loads. The observed changes in longitudinal strain show total change in strain, not strain due to load stress alone.

This discussion has shown the varying conditions of load distribution and restraints which are encountered with normal slab dimensions, and the need for slab design methods which make possible judgment in regard to slab behaviour. Sector Analysis appears to give suitable analytical data for design judgment, which are not given by the various theoretical formulas appraised by the authors. The presently published very approximate constants for Sector Analysis[2] could be greatly improved with modern computation techniques.

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EARLY SOIL-CEMENT RESEARCH AND DEVELOPMENT[a]

Discussions by Carlton N. Conner, C. W. Britzius, K. B. Woods, L. S. Blake, H. F. Clemmer, E. J. Kilcawley, Ellis Danner, D. J. Maclean and Pitt H. Jones, Rupert L. Springenschmid, V. J. Brown, H. F. Winterkorn, and W. R. Thomson

CARLTON N. CONNER,[1] F. ASCE.—This paper with its listed references is an unusually complete and accurate document. It provides authenticated information on soil-cement road work that is readily understandable and usable by the practicing engineer as well as the college student who must learn so much in so little time.

The Portland Cement Association, State Highway Departments, Bureau of Public Roads, Highway Research Board and others participated in the development and use of this remarkable construction material but its present wide field of usefulness would not have been attained without the persistent and painstaking efforts of the author over the past 20 or more years.

In 1928 the writer completed an investigation and report on low cost improved roads which was published by the Highway Research Board. There was then an immediate need for a large mileage of low cost roads which could be improved with successively higher type surfaces as required by increasing traffic. The investigation showed conclusively that utilization of local, short-haul, materials as surfacing or aggregate was the principal factor in keeping construction and maintenance costs at a minimum. Then as now a road surface consists essentially of binder and aggregate. But up to that time 1928, Portland cement had very little use in the low-cost roads. This was because the Portland Cement Association as well as the then more progressive State highway departments were opposed to the use of Portland cement as a binder for any but high type pavements containing such hard, durable coarse aggregates as crushed stone, gravel and slag.

Areas greatly in need of roads but which had only fine grained soils locally available for aggregate were unable to pay for high type pavement using expensive shipped-in aggregates. It was not strange therefore that North Carolina in 1922 turned to sand-asphalt and South Carolina in 1935 to soil-cement as low cost pavements utilizing local, short-haul aggregates readily available in the coastal plain areas. Both types of pavement have been greatly improved as a result of later experience and research.

At first it was thought that soil-cement could serve without the protection of a bituminous wearing surface, but this was not the case. The surface of a soil-cement base is friable and must be protected from the wear and tear of

a. Proc. Paper 1899, January, 1959, by Miles D. Catton.

1. Formerly Chairman, Dept. of Design, Highway Research Board, Washington, D. C. Presently Member of Dept.

motor vehicle tires which scar and ravel it. Wearing surfaces on soil-cement bases range all the way from bituminous surface treatments suitable for light traffic to high type asphaltic plant mixtures or Portland cement concrete heavy duty pavements. Soil-cement bases are commonly six inches in thickness but thinner sections have been used. Thickness is determined as a result of experience in service and suitability to the construction methods used for obtaining maximum density in one course under compaction by sheepsfoot and other type rollers.

The author and his co-workers are largely responsible for the development of tests and specifications for the design and use of soil-cement mixtures which have been approved by ASTM and AASHO and are used by most highway departments.

Wide ranges of soil are used satisfactorily in soil-cement mixtures. They may be classed as:

1. Sandy and gravelly soils having 10 to 35% combined silt and clay.
2. Sandy soils deficient in fines, such as beach sands, glacial sands and wind-blown sand.
3. Silty and clayey soils.

Most of the soil-cement pavements constructed in the United States have soil gradings within the following limits:

Seive Designation	Per Cent Passing by Weight
3 inch	100
No. 4	55 - 100
No. 40	15 - 100
No. 200	0 - 50

Sandy and gravelly soils require lower amounts of cement than silty and clayey soils. The amount of cement for heavy clay may be so great as to preclude its use as aggregate in a soil-cement mixture.

While approved test methods result in a predictable and dependable construction material they are slow, time consuming and require large samples. As a consequence researchers are trying to improve on existing methods that will provide short-cuts for determining the cement requirements for sandy as well as clayey soils. There is good reason to believe that certain additives such as lime and lime-fly ash are beneficial at low cost; also that proper identification and comparison of soils for soil-cement mixtures can be based on the pedalogical system developed by the U. S. Department of Agriculture, which in turn becomes a reliable indicator of cement requirements for soils taken from widely separated areas.

Quite recently the Highway Research Board published its Bulletin 198 which gives the results of research on a short-cut test method developed by the Portland Cement Association and a rapid method of predicting Portland cement requirement for stabilization of plastic soils by researchers of the Bureau of Public Roads.

The author has presented a paper outstanding in its thoroughness, technical discussion and explanation of the principles involved.

C. W. BRITZIUS,[1] F. ASCE.—This paper is an excellent and accurate history of the development of soil cement. The bibliography will be especially useful. The writer was reminded of the separate criteria that has been developed when soils are to be only "cement modified", and in which the fines of granular soils and fine grained soils are to be altered to be less moisture susceptible. A desirable addition to the paper would have been more information concerning the cost, both for cement and construction, of treating various types of soil. The writer is aware that granular soils containing at least 5% minus #200 (10% if fine sands) are the easiest to process and require the least cement. Clean sands are improved by the addition of fines. The processing of clay soil is not usually economical because of the high cement contents required and the difficulty in processing.

The writer would like to make an additional comment or two regarding soil cement. It is not felt that the pedalogical approach to soil classification is the best. It is suggested that soils be classified on the basis of geologic origin. The various glacial drifts are the parent soil in Northern United States. Whether these soils are unsorted or rewashed is important. Residual, alluvial and aeolian origins should also be a basis of classification. These classifications all obviously relate to particle size distribution. Because soils to be treated as soil cement more often than not come from horizons below C, this latter approach seems to be desirable. The writer also feels that the structural strength of soil cement has not been properly evaluated as to its relation to load bearing capacity and the thickness required for a given subgrade strength and wheel loading.

K. P. WOODS.[2]—This paper is a timely resume of the development covering the use of mixtures of soil and cement primarily for highway and airport runway construction. In considering the current widespread use of soil-cement it is difficult to visualize that the entire development of this product was started something less than thirty years ago.

It has been this writer's privilege to have followed some of the early subgrade treatment work done in Ohio.(1) In the early 1920's Professor F. H. Eno of the Ohio State University had observed that there was an important relationship between the type of soil and the performance of various kinds of highway pavements under traffic and weathering. For this reason, in cooperation with the Ohio Department of Highways, he made a great many subgrade installations throughout many parts of Ohio. Such a section on U. S. 50 between Marietta and Athens, was constructed in the fall of 1924. Included were three sections of "cement clay," one two-inches thick, a second four-inches thick and a third six-inches thick. The surface pavement was a 9-7-9 inch concrete pavement.

Interestingly enough, a survey made in May 1934 indicated that the "cement clay" sections performed very well on the basis of amount of cracking of the concrete pavement for the cement-clay, subgrade-treated sections as compared with the untreated sections. Had the concept of adequate compaction been known in the early twenties, Eno probably would have discovered "soil-cement."

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1. Pres., Twin City Testing & Eng. Lab., St. Paul, Minn.
2. Head, School of Civ. Eng., Purdue Univ., Lafayette, Ind.

Much credit should go to the Portland Cement Association, many highway departments, universities, and other researchers for the development of this new structural material known as soil-cement or as cement-hardened soils. Much credit is due the author for his untiring efforts for many years in this development work.

REFERENCE

1. Eno, F. H., "Some Effects of Soil, Water, and Climate Upon the Construction, Life, and Maintenance of Highways," Engineering Experiment Station, The Ohio State University, Bulletin No. 85, November 1934.

L. S. BLAKE.[1]—Many engineers throughout the world who are interested in soil-cement work will be grateful to Mr. Catton for this account of 24 years of intensive research.

Although there are certain differences in approach, British soil-cement technology was largely based on the work described in this paper and, therefore, it is especially useful to have an authoritative history of research into the subject. There is no doubt that this most recent paper by the author will assist many of us by providing a suitable background against which to study the detailed results of his excellent research.

The author has stated that the cement content required for successful and economical stabilization is determined by durability rather than by structural strength considerations. In Great Britain, where frosts are generally moderate but moisture changes may be considerable, durability tests are not often required and the cement content required to give a 7-day compressive strength of about 250 lb/sq. in. is also almost invariably adequate to provide the necessary resistance to damage by frost or by moisture changes. Durability tests are made on soil-cement when the natural soil is known to be susceptible to damage by frost, for example on soft limestone or chalk, or silts and fine sands or when the natural soil is especially susceptible to damage by moisture changes. It would be interesting to know the extent to which differences in climate were taken into account by the author in deciding criteria to be applied to the durability tests. Are the same criteria applied throughout the U. S. A. even although some states may have no frost and others no serious moisture change problems?

The use of soil-cement bases in Great Britain is growing steadily and including a motorway contract, several airfield runways, bases to factory floors and roads of all types. The performance of soil-cement in Great Britain has been excellent and the remarkably low incidence of failure bears testimony to the author's contention that satisfactory laboratory testing methods have been developed to provide all the information required for constructional work. However, it is to be hoped that future research will lead to simplification of and reduction in the time required for laboratory tests prior to construction. It may well be that a closer study of the surface chemistry of soils will secure the next major advance by providing explanations for inconsistencies found when examining the influence of the physical properties of the soil on density strength and durability.

1. Roads Dept., Research and Development Div., Cement and Concrete Assoc., London, England.

We can confirm the author's findings with regard to the need for limiting the delay between mixing and the completion of compacting soil-cement but we have found that the loss in density, and consequent loss in strength due to delay, is much greater for cohesive soils than for granular soils. Laboratory tests by the Cement and Concrete Association have shown that by delaying compaction for 2 hours the strength can be reduced by as much as 50% for cohesive soils but the corresponding loss for a cohesionless sand is almost negligible. These results are perhaps contrary to what one might have expected but they have been confirmed by similar tests made at the Road Research Laboratory. Perhaps the author can offer some explanation for the different effects of delayed compaction on these soils? The importance of good compaction on the site cannot be overemphasized because of the influence of voids on both strength and durability.

H. F. CLEMMER,[1] F. ASCE.—The author is to be congratulated on the general excellence and the thoroughness of his presentation. The paper traces the engineering development and evolution in the technical theory and practice of this important construction material and contains information of definite value to engineers since it is a complete resume of the work to date.

Certainly no one is more qualified than Mr. Catton to prepare such an article, since he has been closely associated with this work from its inception. The testing procedures of the American Society for Testing Materials represent a tremendous effort by numerous individuals; however, their current status and initial development were promulgated by the author.

It is of importance to emphasize the material contribution to soils engineering field of the moisture density relationship of soils that was a direct by-product of the work on soil-cement. It is a singularly important contribution which has general acceptance today in control of compaction of embankments and one of which the writer has personal knowledge.

It is believed that the article will provide engineers and researchers an excellent starting point, since the presentation is authoritative, resourceful, of the highest quality, and a factual presentation of the subject.

E. J. KILCAWLEY,[2] F. ASCE.—This paper presents in clear, concise form the scientific and engineering principles involved in the development of soil-cement as a predictable and dependable construction material. It represents several years of intensive work in both theoretical study and research and contains information of inestimable value to future members of the engineering profession.

The Portland Cement Association well deserve the grateful thanks of the engineering profession for the inauguration of the extensive program in research and development of soil-cement in 1935. This was done in spite of the fact that over a period of nearly twenty years methods used failed to produce a material of predictable physical and mechanical characteristics.

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1. Engineer of Materials and Research, Engineering Department, District of Columbia Government, Washington, D. C.
2. Professor and Head of the Div. of Soil Mechanics at Rensselaer Polytechnic Inst., Troy, N. Y. Chairman of A.S.T.M. Committee D-18 on Soil for Eng. Purposes.

Mr. Catton who served the Association as director of this investigation deserves the highest professional commendation for his thorough scientific yet practical guidance of this development.

The technical problems to be solved were tremendous and must have, at that time, seemed insurmountable. The probable reactions of various types of soils were not well understood. Little was known of the complicated reactions due to surface forces. The complex reactions of hydration of the cement relative to the soil, in the presence of varying moisture content and degree of compaction were unknown.

Recognizing this lack of knowledge and the fact that multiple phase systems of soil and cement solids, water and air would be produced, a scientific approach to the solution of these problems was planned. It included a study of and the application of the pedological system for identification and classification of soils; an extensive study of the surface chemistry of soils, the determination of moisture-density-compaction relations and the establishment of the quantity of cement necessary to produce a dependable structural material in which the moisture content was variable. The results of these and other studies has made possible a clearer understanding of the physico-chemical reactions involved.

The paper itself together with the excellent list of references clearly shows the thoroughness with which this investigation was conducted from both the theoretical and practical points of view. It also shows that more complete records were kept than for the development of any other large scale non-metallic material. Furthermore, it is a most valuable contribution to the civil engineering profession.

At this time, great interest was being shown in the durability of construction materials. It was therefore essential that suitable test methods be devised to determine this property of soil-cement. The efficiency and thoroughness with which this was done is clearly shown by the fact that in 1940 A.S.T.M. tentative procedures for wetting and drying and freezing and thawing tests were established. In 1942 the first test procedure for determining the moisture-density relations of soil was accepted by the Society. These test procedures were prepared under the leadership of Mr. Catton and were accepted, virtually without opposition, by the members of the Societies Committee D-18 on Soils for Engineering Purposes. Mr. Catton is also largely responsible for the advancement of these tests to standards in 1944 and for bringing them up to date in 1957. Thus in the relatively short span of nine years (1935-1944) both technological knowledge and methods of determining the structural strength and durability of a new structural material were established and accepted by the engineering profession.

From the first successful field use of soil-cement as a paving material in 1935 to its present day world wide use and the increasing use of cement modified soils and of plastic soil-cement mixtures attest to the validity of the concepts used in the solution of the technical problems involved in the development of a predictable and dependable construction material. Furthermore, the increasing use of certain established principles such as moisture-density relations is also having a tremendous impact upon soil engineering practice and progress in highway construction.

The development of soil-cement through the scientific study and experimental research together with the necessary quantitative and qualitative tests to evaluate its physical, chemical and durability characteristics represents an outstanding engineering achievement. It is one which may also well

represent a turning point in engineering development. It is not only serving as a basis for further detailed study but could also provide a pattern for research and development of other materials of engineering based upon scientific principles and procedures.

Present day studies and research are being carried on with respect to surface chemistry of soils, the strength and elastic properties of compacted soil-cement mixtures, the cement reaction to various types of soils and other facets of the problem. This work is contributing to a better understanding of the physical, chemical and mechanical properties of both the materials themselves and of the mixtures used.

From the beginning all phases of this work has been of the highest scientific and professional order. It will continue to have a tremendous impact upon engineering and construction practice. Both the association, the author of this paper and all individuals who have contributed can be justly proud of a valuable and continuing contribution to both technological knowledge and the advancement of soil engineering practice.

ELLIS DANNER,[1] F. ASCE.—The term "pavement" as commonly used in highway and airport engineering refers to any combination of materials of one or more layers (may include surface, base and sub-base) placed on the subgrade to provide a suitable surface for the movement of rubber-tired vehicles at relatively high speeds. Any satisfactory pavement must provide the surface properties needed for safe, economical and comfortable vehicular movement and must have the durability to maintain these desirable surface properties for a reasonable economic life.

Pavement design to provide and maintain suitable surface properties includes a consideration of traffic wear on the surface, deformation of the pavement under traffic loads, and the effects of temperature, moisture and chemicals on both the pavement and the subgrade. This design may be divided into "composition design" which is concerned with the selection, proportioning, and control of the combination of materials which will constitute the pavement and "structural design" which considers the deformation of the pavement under repeated loads and the behavior under other stresses to which the pavement may be subjected, in order to determine the proper thickness and combination of layers.

The research and development reported in this paper illustrate the advancement that is possible with the use of scientific methods in the solution of engineering problems and specifically in the pavement materials field. The too often used trial and error method of trying to develop new or better pavement materials by constructing experimental roads and observing performance without adequate preliminary study is a time consuming process and usually adds little to engineering knowledge that can be applied to other situations under different conditions. This paper points out the manner in which new test methods may be found and yardsticks developed which can reliably evaluate characteristics and predict performance with different soils under varying conditions. The development of techniques for producing a material of predictable characteristics for pavement purposes is a real step forward in pavement technology.

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1. Prof. of Highway Eng., Univ. of Ill.

The concepts outlined in this paper for developing acceptable pavement materials have a wide application. It is pointed out that well compacted materials of many types at specific moisture contents have properties quite suitable for pavement purposes. If these properties can be maintained over a reasonable length of time by the addition of other materials, whose effects can be reliable predicted, a satisfactory pavement material will result. To be assured of good results reliable tests are needed which will predict pavement behavior under the conditions to which it is to be subjected during its expected life. Such tests have been worked out for soil-cement mixtures and they may be used with modifications on other materials.

This research emphasized the significance of the moisture-density relationship in the control of composite materials used for construction purposes. Highway embankment as well as pavement construction has no doubt been influenced by and benefited from the work done in the soil-cement studies.

The paper also serves effectively to point out the need for additional research in the soil-cement area as well as the pavement field in general. The writer concurs with the statement regarding the importance of future research relating the influence of surface chemistry of soils on the behavior of soil-cement mixtures. While this excellent research reported upon provides the data for effective composition design of soil-cement mixtures, corresponding research and development to determine the behavior of soil-cement bases under traffic loads are needed to bring structural design methods up to the same level. Studies are needed to correlate compressive strengths with deformation characteristics under load, to evaluate fatigue effects of repeated loads, and to study crack formation and control.

This paper represents a significant engineering advancement in the pavement field and is a milestone in highway progress. It sets a pattern for the use of scientific methods for analyzing and evaluating the many factors which may influence the behavior of pavement materials and for reliably predicting the performance of these materials under field conditions. The development of better pavements for many uses can be speeded up considerably if the type of research discussed in this paper is as effectively applied to other materials and to other phases of the pavement design problem.

D. J. MACLEAN,[1] and PITT H. JONES.[2]—In both the laboratory testing of soil-cement, and in the construction procedures, a critical problem is the selection of the appropriate moisture content at which to compact the mixture of soil and cement. With predominantly granular soils stabilized with cement the primary aim is to achieve a high dry density and, since the optimum moisture content of these soils using the A.S.T.M. test does not differ significantly from that obtained with compaction plant, this moisture content is reasonably appropriate for both laboratory and field work with such soils. With cement-stabilized cohesive soils, on the other hand, it is suggested that the selection of the moisture content for compaction should be based not only on the need to obtain a high state of compaction but also to minimize the effect of expansive forces due to the absorption of water subsequent to the hardening of the material. For this reason, in the United Kingdom, cement-stabilized cohesive soils are compacted at a moisture content higher than the

1. Road Research Laboratory, Harmondsworth, England.
2. Military Engineering Experimental Establishment, Christchurch, England.

optimum moisture content for A.S.T.M. compaction, and a convenient value is usually found to be 2 per cent less than the plastic limit of the soil-cement mixture. In the laboratory the compressive strength is determined of the soil-cement mixture fully compacted at this moisture content.

The above procedure used with cohesive soils differs from the American procedure in which the material is compacted at the optimum moisture content and then subjected to test techniques which allow the expansive forces due to presence of clay to damage the soil-cement. We regard this as being unsatisfactory, certainly for British conditions, since the test technique puts undue emphasis on a form of deterioration resulting from an effect of minor significance in practice. In fact, the very few failures of soil-cement pavements in the United Kingdom have resulted mainly from the compaction of the material at too low a moisture content, thus providing the condition for its subsequent disruption.

With regard to the evaluation of compacted soil-cement mixtures the view is taken in the United Kingdom that the material must first have an adequate shear strength and must secondly be durable against the action of frost. In research carried out in 1939 at the Road Research Laboratory it was established that laboratory soil-cement specimens with an average compressive strength of not less than 250 lb/sq. in. at 7 days were capable of withstanding the American durability tests, and this strength was therefore adopted as a basis for designing soil-cement mixtures for road bases. Experience over the last 20 years has shown that soil-cement designed in this way has proved strong and durable enough for light and medium road traffic conditions. For very heavy traffic on main trunk roads there is some evidence which suggests a rather stronger material is desirable—one with possibly an average laboratory compressive strength of the order of 400 lb/sq. in. at 7 days. The use of compressive strength criteria in the United Kingdom has certainly not led to the use of excessive cement contents.

In British overseas territories, particularly in Africa, there are great potentialities for the use of soil-cement in road construction, and here the trend is to use a modified form of the California bearing ratio test for designing soil-cement mixtures. Laboratory C.B.R. values of the order of 120 to 180 per cent at 7 days have been suggested as a basis for designs and these values are supported not only by practical experience but also by the results of laboratory research which shows that for many soils these C.B.R. values are in broad agreement with the requirement of a compressive strength of 250 lb/sq. in.

The compressive strength and C.B.R. tests and other tests to determine the resistance of soil-cement to immersion in water and to the action of frost are all described in British Standard 1924:1957.

Considerable attention has been given, both at the Road Research Laboratory and at the Military Engineering Experimental Establishment to the chemical interference with the hardening of soil-cement by certain organic fractions in the soil and, although research continues into the chemical methods of detecting these fractions, the parallel research into the pedological identification of soil suggests that this will provide a simpler solution to the practical problem. A detailed study is being made at the Road Research Laboratory and this has shown that by a simple visual recognition of which of the five major groups in the United Kingdom a given soil profile belongs, it is possible to judge quite accurately the depths below the ground surface at which soil sufficiently free from organic contamination occurs. The pedological

identification of a soil thus obviates an earlier difficulty of wasting effort through sampling at a depth too near the surface. In some instances soils down to a depth of 5 ft may be unsuitable for stabilization because of the presence of organic matter.

It is sometimes found more economical, even in the case of mix-in-place stabilization, to import better material from nearby sources than to stabilize the in situ material. This arises particularly with organically contaminated soils where not only is there a saving in cement but a much more uniform pavement results. Selection of the suitable borrow material is in such cases greatly aided by pedological soil identification.

The present state of research into the effect of organic matter in soils indicates that it interferes with the hardening of Portland cement by the absorption of calcium ions from the hydrating cement and thus produces a lowering of the pH. This latter effect seems likely to provide a basis for recognizing the presence of deleterious organic matter in soils.

RUPERT L. SPRINGENSCHMID.[1]—Soil-cement was successfully used during World War II by the German Luftwaffe for the construction of runways in almost all occupied countries—especially in Russia—where varying conditions of soil and climate were prevailing. More than one hundred stabilising machines were produced according to different designs. Most of them were of the single-pass mixed-in-place type. However, only two of these machines have survived in Western Germany. Soil stabilisation was discontinued after the World War II until in the early fifties the rapid increase in German traffic made low-cost highway construction a necessity. Now soil-cement is used largely for new autobahns and farm-to-market roads.

The recommendations made in Catton's paper are surprising in as much as the paper states that the moisture content of a soil-cement mixture—when being compacted—should not be below nor exceed one fifth of the optimum moisture content as determined in the Proctor moisture-density test. Comparative tests of the "Forschungsinstitut der Zementindustrie" in Duesseldorf have shown, however, that optimal compressive strength in stabilising sandy soils is obtained with a water content remaining two or three percentage points below the optimum moisture, when compacting as specified in the Proctor moisture-density test. Specimens with water content below optimum resulted in lower density but higher compressive strength than found in specimens compacted at optimum moisture content for maximum density. With silt-and clay-soils highest compressive strength was obtained with a water content of one to three percentage points above optimum moisture. As a soil-cement mixture reaches its optimal durability at highest compressive strength this factor should always be kept in mind.

In the section "Construction Control" Mr. Catton recommends that during field construction compaction must be completed within two hours and the total time-lapse between the spreading of the cement until compaction is completed shall not exceed six hours. The mentioned tests made in Duesseldorf (when using sandy soils) showed no detrimental effect, when the compaction work exceeded the given limit by one or two hours. With cohesive soils, however, it was found to become very difficult to obtain maximum density (as it

1. Forschungsinstitut der Zementindustrie, Dusseldorf, Germany.

would be obtained in case of compacting immediately) if the total lapse of time exceeds four hours. Some American specifications recommend the determination of optimum moisture and maximum density by tests made in the field shortly before damp mixing is completed, in order to obtain the required field control data. Tests including both, sandy as well as cohesive soils have shown that the detrimental effect of time-lapses between mixing and compaction of a soil-cement-mixture—when they exceed the given ones—cause only a slight reduction in compressive strength, provided that the compactive effort is high enough to produce the same dry density otherwise obtained by the Proctor-method immediately after mixing. With cohesive soils, however, a particularly high compactive effort is required to obtain the same maximum density after several hours as it would be obtained in case of compacting immediately. If, however, for the construction in the field a maximum density is specified which is determined by a several hours damp mixed material, a considerably lower density must be expected. Lower density of the soil-cement-mixtures in the field results in lower strength and lower durability than found for mixtures tested in the laboratory.

Mr. Catton's paper made no mention of cracking. Many soil-cement subbases show cracks very early after construction or during the first winter. The cracks are often of the alligator-type. Sometimes however transversal cracks occur, which are 50 feet or more apart. These cracks will open when temperature goes down and then break through the asphalt concrete surface. As a result, water penetrates into the subsoil, requiring repair work to seal these cracks. Most probably transversal cracks will mainly arise in soils of the sandy type when stabilisation work is done during the hot summer period. Field engineers would be highly interested in getting exact data as to when transversal cracks—opening widely—must be expected. Not only would they wish to eliminate subsequent seal work, but likewise the unpleasant look of a newly build road.

V. J. BROWN,[1] F. ASCE.—In this paper there has been outlined the development of a most useful, lower cost type of road base. The controls and construction procedures are required for most economical and best results. When this stabilization procedure was first introduced, and for quite a few years afterward, ordinary farm type tractors and spring tooth harrows were employed for the pulverizing and mixing process. We have come forward several steps since those days.

One of the keys to successful soil-cement mixtures is the pulverization of the soil and the intimate mixture of cement with the pulverized soil. Too frequently this part of the construction procedure is not rigorously followed. In the third paragraph of the subheading "Moisture-Density Relations of Soil and Soil-Cement", Mr. Catton states: "The most important aspect of the Proctor moisture-density concept was that by compacting soil to maximum density at optimum moisture content, the optimum structural strength and load-carrying capacity of the soil will be attained." Many researches have shown that there is no relationship between density and soil supporting value (load-carrying capacity). The inference that the greater the density, the greater the load-carrying capacity is not necessarily true. However, since there are several different methods of testing for density-optimum moisture, by

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using other than the Proctor test, all of which produce greater densities at lower moisture contents, it is true for all practical purposes in the Proctor test. I do not mean to detract from the value of this paper by the remarks just above, but rather to point out that there are several different testing procedures and that high density does not necessarily imply high load carrying capacity.

I have followed this useful base construction from its inception. The soil-cement base is a contribution to the art of economic road building. What makes the mixtures of soil and cement so useful is the many studies that were made on all types of mixtures such that definitive specifications for quality control can be prepared. The wet-dry and the freeze-thaw tests were developed by Mr. Catton such that dependable, reproducible, and interpretable results can be obtained.

In the early days of the development of the construction procedure, emphasis in the highway field was on the need for low-cost roads. To keep costs low, discs, disc harrows, spring-tooth harrows, spiked-harrows, pull graders, motor-graders, gravity type sprinkling trucks, and sheepsfoot rollers were employed. Scarifiers and rippers, along with the harrows, attempted to pulverize the soils. Bags of cement were spotted at calculated places on the prepared soil, opened by hand, and dumped. The harrows and graders prepared the mixtures as best could be done with them. Water was added more by estimate than by measure and the graders mixed and spread the materials. In those early days, the sheepsfoot roller was highly recommended for compaction with the point in mind of rolling until the feet rolled out. Then the top inch of fluff material was scraped by a spike-tooth harrow to remove what was stated to be "cleavage planes". Then followed the steel wheel roller after wetting.

All of this has changed to procedures now used that more nearly give pulverization, intimate mixture, and measured water content. While the sheepsfoot roller is used at times, so are other types that meet the theoretical requirements for compaction of the type of soil being used.

HANS F. WINTERKORN,[1] F. ASCE.—Modern soil-cement is a remarkable construction material. Aside from its physical and chemical properties, it is noteworthy because of the fact that, from its early infancy in South Carolina to its present world-wide use, its development enjoyed close scientific and engineering guidance and that more precise records have been kept on it than on the development of any other large-scale construction material. The man primarily responsible for the strategy and tactics of this development was Miles D. Catton of the Portland Cement Association. He was like a general with a few regular officers sent to organize, inspire and lead the militia and the natives. This job called for a man with an intuitive understanding of construction materials and sufficient faith to keep in the lead when the going was rough, a man with infinite capacity for hard work and respect for the importance of details, a man of much patience and strong motivation. Mr. Catton filled these qualifications in every respect and what he and his associates of the Portland Cement Association accomplished has become a classical example for outstanding leadership of a trade association in the development of a new use for an established product.

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Mr. Catton's paper is a condensed account of the achievements during his generalship. This account is so concise and so well fitted together that it is hard for the critic to detect the sutures or to find locations suitable for dissection and analysis. The best he can do is to tap the various parts of the structure with his critical hammer and to listen to the sound.

1. Properties of Soil Cement

The author restricts his account on this and the other phases to the explanation of the "philosophy" of soil cement technology as resulting from the Portland Cement Association's research and development program. This philosophy has both tactical and strategic elements with the former playing a greater actual role in the development. It was for such tactical reasons that the concept of soil-cement as a material having its own unique properties was emphasized and comparison of soil-cement and concrete deferred during the development. However, there seems to be no good reason why the types of soil-cement as presently understood to exist should not now be given in their relationship with previously known construction materials. Thus we have two general categories of soil-cement which are characterized by the presence or absence of a skeleton of gravel plus sand or sand size materials. With such a skeleton the stabilized soils are akin to concretes and plasters and follow the laws found for these by Feret, Fuller, Rothfuchs and others.(1) Actual uniqueness could be claimed only for cement-stabilized silt-clay soils that do not possess a skeleton of coarse-grained primary mineral particles but in which natural or artificial secondary soil aggregations consisting mainly of silt and clay particles are endowed with greater mechanical strength and water resistance by the admixed cement which also glues the stabilized secondary particles together to larger structural elements.(1)

2. Moisture-Density Relations of Soil and Soil-Cement

Recognition of the applicability of Proctor's moisture-density relationships for specified type and amount of compactive effort to soil-cement systems was an excellent starting point for the Portland Cement Association's research and development work. It was a lucky accident that the compactive effort in the Proctor method was low enough to require optimum moisture contents that were ample to satisfy both the water affinity of the soil particles and the hydration requirements of the cement grains. Even then, in the case of soils having a long plateau in the moisture density curve, use of the maximum amount of water compatible with the maximum density was found desirable. Fear of insufficient water in the case of maximum densities obtained with greater compactive efforts, as in the modified Proctor tests, prevented full utilization of the benefit of higher densities actually achievable in the field. This problem is still with us. Its practical solution calls for a better knowledge than presently available on the condition of moisture in cohesive soil systems and on its modification in the presence of portland cement.(2;3) This, however, does not detract from the great merit of making the Proctor method an integral part of soil-cement technology.

3. Factors Governing Tests

Excellent engineering judgment and deep insight into the behavior of porous, hydrophilic, cemented construction materials were shown in the development

of the freeze—thaw and wet—dry tests as primary standards for the quality of soil-cement systems. These, of course, grew out of the recognition of the major importance of durability which at that time also became the major concern of concrete technology. Secondary standards in the form of compressive strength tests are admissible only to the extent to which they have been linked to these primary standards. The wet-dry and freeze-thaw tests probe fundamental properties of soil-cement systems and do more than just duplicate exposure to naturally occurring wetting and drying and freezing and thawing cycles. Even when, for instance, freezing and thawing does not occur in a specific location the freeze-thaw test should be used since it probes for weaknesses in a system which otherwise appear more slowly but no less certainly under naturally occurring temperature fluctuations above the freezing point. An important finding in the application of these tests was the existence of minimum or threshold values in cement contents at which large changes in the properties of treated soils occur. Their existence, which has been found also in other cemented systems, should serve as a cautioning signal in essaying the permanent value of the often surprising effects that small admixtures of active materials may show in early strength tests. If the tremendous effects of small amounts of vitamins and hormones in living systems should be held up in argument against such conclusion, one should keep in mind that in such systems the highly active materials must be continuously renewed.

Surface Chemistry of Soils

Mr. Catton justly points out the importance of the surface density of soils and the difficulty in quantitatively assaying its role. This role is basically different for systems possessing a granular skeleton and for those lacking such a skeleton. For the former it is enough that the surface-chemically desired water affinity of the silt-clay materials in the presence of cement hydration products is small enough not to push the coarser skeleton-forming particles apart. For such systems different optimum clay contents have actually been found for different types of clays, the actual amounts decreasing with increasing water affinity of the clay minerals. In other words, volume relationships are determinant.(4,5,6)

In systems lacking a coarse-granular skeleton, the particles that are cemented together are secondary natural or artificial structural units that themselves consist of aggregated clay, silt and even sand particles. These secondary structural units are infested and case-hardened by the hydration products of the cement and are glued together by the latter. The surface-chemistry acts, therefore, not directly but indirectly through its effect on the strength and water-affinity of the secondary aggregations. This was clearly brought out in the work at the University of Missouri cited by Mr. Catton.(2) In other words, the stronger and the more water resistant the secondary aggregations are, as long as the water resistance is not due to organic coatings as in a chernozem soil, the easier they can be stabilized by means of Portland cement.(7) The stability of secondary soil structural units is a pedological property and hence dependent not only on the type and amount of mineral soil constituents, their exchangeable ions and the composition of the soil water as well as on the amount and type of organic matter, but also on all other soil genetic factors. It is for this reason that the Portland Cement Association workers as well as Mr. Hicks of North Carolina, and others have been able to find such close relationships between genetic soil types and susceptibility to

stabilization by means of Portland cement. Hence, except where certain specific substances affect directly the rate of hardening of the cement paste, soil-chemical factors act indirectly through their influence on the morphology of the original soil systems and on the crystallization habitus of the cement hydration products.(7)

Determination of Cement Requirements and Construction Control

The methodologies developed by the Portland Cement Association in cooperation with other agencies are admirably suited for the purposes intended. This is attested by the high quality achieved in soil-cement construction whenever these methods have been applied with engineering judgment.

Cement Modified Soils

Upgrading of cohesive soils by granulation of their clay and silt components to mechanically strong and water resistant secondary particles of sand size by the admixture of small amounts of Portland cement is a good method as long as soil composition and condition of exposure are of a kind to assure permanence of such granulation. Caution is indicated in acid soils in which organic matter has accumulated in the absence of Ca - ions, i.e. by retardation of bacterial activity. In such cases addition of cement by supplying needed Ca - ions may stimulate bacterial decomposition and may if the soil is covered by a pavement of low water permeability actually result in an increase of the plasticity of the soil. Such soils and conditions can, however, be easily recognized and avoided. Admixtures of small amounts of Portland cement to sandy soils may aid in the ease of their densification and in the retainment of the achieved density.

Plastic-Soil Cement

Plastic soil-cement of the consistency of masonry mortar is an interesting newer development with important actual and potential uses. Because of its higher moisture and cement content it is akin to normal cement mortars in the case of sandy soils that possess a granular skeleton. In the absence of such a skeleton with silt and clay soils it can be expected that the surface chemistry of the soils will affect the systems more directly than through the morphology of secondary soil structural units.

SUMMARY

It is very fortunate that a man of the experience and status of Mr. Catton has taken time out to tell the story of one of the most important developments in modern highway construction materials in which he himself played a leading role. This is an engineering and human document of highest importance.

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W. R. THOMSON.[1]—The writer was very interested to read this paper particularly as so much of the pioneer work in this form of construction in England has been carried out in the county of Worcester. At the moment too, we have under construction a new motorway which includes a section about 6 miles in length with the carriageway foundations constructed in this material.

The methods of testing and control in this country seem to be very similar to those described by Mr. Catton, and indeed I find very little to comment on for this reason. It may perhaps be of general interest however, to describe the work as it is carried out on our present motorway contract, particularly as this is the first occasion in this country where soil cement has been used to this extent on a road of such importance.

The carriageway construction thickness is designed in accordance with the California Bearing Ratio method, using a 20,000 lb. wheel load curve. The soil which is being stabilised is a Keuper Marl or silty clay, having a Casagrande Classification of CL or CI, and in order to obtain the required design depth, two-layer construction is being adopted. The upper layer is a constant thickness of 6" throughout, the lower layer varying from 4" to 6" depending on in situ C.B.R. values. Where these values are low a 12" layer of granular material is used below the soil cement to give the required thickness. The "black top" consists of 4" of bitumen macadam with an asphalt running surface.

After the cuttings and embankments have been formed the lower layer of soil cement is produced by mix in place construction on the formation level, using 5% - 7% of ordinary Portland Cement, and it is not considered necessary in this case to specify a crushing strength. The top layer of soil cement is formed by bringing in material from adjoining cuttings, spreading and giving initial compaction and shaping to levels, followed by stabilising by mix in place

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methods using 10% of cement. In this case a crushing strength of 250 - 650 lbs. per sq. inch is required and the cement content may be varied accordingly to give this figure. In both layers the mix in place is carried out with a single pass machine using dropping weight compactors, followed by an 8 - 10 ton roller. The single pass machine completes a width of 6 feet in one pass, and following the rolling a curing coat of cold bitumen emulsion and sand or grit is applied, after which no traffic is allowed on it for 7 days. The degree of pulverisation is such that 80% of the material is to pass the 3/16" standard mesh sieve.

Soil cement construction on this 6 mile contract is only in its early stages, and so far only the lower layer has been attempted. Work was commenced last autumn, but had to be abandoned following a spell of exceptionally wet weather, thus indicating a serious limitation in its application if construction under all-the-year round conditions is required. The short section which was completed was left for the whole of the winter with no protection other than the curing membrane, but when subjected to C.B.R. tests in the early spring gave results beyond the range of the testing apparatus to record.

The moisture content at which the compaction is carried out is required to be within 2% of the optimum for the plant and the particular soil, in this case about 20%. The density required is to be 95% of figures obtained in preliminary trials, and tests are also required for organic content, liquid and plastic limits and cement content, in addition to those for crushing strength pulverization and C.B.R. values already mentioned. The carrying out of these tests and the close control of the work in progress which is required can be quite a considerable item by comparison with other forms of construction. A particular point which is found to require very careful supervision is the accurate shaping of the formation which is required before the processing is commenced in order that irregularities shall not be repeated in the finished layer.

A matter in connection with soil cement on which there is a serious lack of information in this country, and which Mr. Catton does not touch on in his paper, is its treatment in connection with pavement design. In common with other semi-rigid or semi-flexible methods of construction it receives the same consideration in relation to the C.B.R. curves as do the purely flexible forms of construction. It is hardly reasonable to expect a subject of such further complexity to be covered in the paper, but it would be very interesting to know if more work has been done in the United States in the way of experiments and trials to establish beyond doubt whether any reductions in pavement design thicknesses can be contemplated when using soil cement compared with what would be required with a purely flexible pavement.

HW 3

HIGHWAY-TRAFFIC ESTIMATION BY LINEAR PROGRAMMING[a]

Discussion by Ming L. Pei

MING L. PEI,[1] M. ASCE.—The author has attempted to analyse traffic volumes at a highway interchange by linear programming. Unfortunately there are two objections to the author's paper which cast grave doubt as to the validity of the author's method as well as the results.

The mathematics of algebra provides the method to solve a set of simultaneous linear algebraic equations. One must, however, set up these equations based on the physical principles governing the problem under study. It would be absurd, having set up 4 equations containing 5 unknowns, to say, "Ah! Algebra demands 5 equations here. Let us dream up another equation, even if we cannot derive it from physical principles." Needless to say, the validity of the solution depends on the validity of the original equations.

The new mathematics of linear programming is, in a manner of speaking, an extension of algebra. It enables one to solve a set of simultaneous linear algebraic equations or inequalities, together with the maximization of an objective function. Unlike algebra, it will handle inequalities as well as equations. Furthermore, there may be more unknowns than equations (or inequalities). Generally, there are an infinite number of sets of solutions. By linear programming, we can find the particular set of solutions such that the objective function, such as,

$$c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4 + c_5x_5 + c_6x_6$$

assumes a maximum (or minimum) value. Once the set of equations (or inequalities) together with the objective function are derived from basic principles, linear programming will provide the mathematical operations to obtain the solution. It is absolutely essential that an objective function is given, before one can apply linear programming. In analyzing how best to operate an industrial plant, the objective function may the profit, which we hope to maximize. In solving a structural problem, the objective function may be the strain energy, which, according to known physical principles, is a minimum. In any case, we must be able to justify, based on the nature of the problem, why an objective function should be a maximum (or minimum). It is meaningless to maximize "something, anything" just because we need one in order to apply linear programming. Needless to say, there are problems where there is no objective function.

What is the objective function in a traffic interchange problem? What function of traffic volume is a maximum? The author states, without explanation or elaboration, that the objective function is,

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a. Proc. Paper 1900, January, 1959, by Edward L. Killin.

1. Associate Prof., City College of New York, New York, N. Y.

$$c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4 + c_5x_5 + c_6x_6$$

where x's are the volume of traffic in each of the six directions, and c's are the draw factors in each of the six directions. The draw factors are defined as follows:

$$\text{Draw Factor} = \frac{\text{Population}}{\text{Distance}^2}$$

Why is the summation of the products of draw factor and traffic volume a maximum? Can this be proved? Are there factual evidence to show that this is a reasonable assumption? This is a crucial point; for without an objective function, it will be futile to solve the traffic interchange problem by linear programming.

The Seymour Interchange analyzed by the author is shown in Fig. 1, where x's are the volume of traffic making any movement, and b's are the total traffic volume along a given road. Obviously these facts can be expressed by the author's Eqs. (1) to (5).

$$x_1 + x_2 + x_5 = 4,140 \quad (1)$$

$$x_2 + x_3 + x_6 = 6,240 \quad (2)$$

$$x_3 + x_4 + x_5 = 4,680 \quad (3)$$

$$x_1 + x_4 + x_6 \geq 6,000 \quad (4)$$

$$x_1 + x_4 + x_6 \leq 8,000 \quad (5)$$

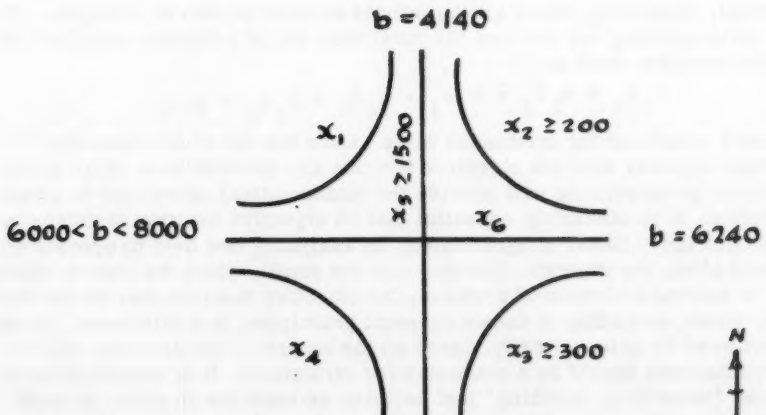

Fig. 1. All Given Data

In addition, the minimum value of traffic volume in three directions are assumed to be given. (The minimum value of traffic volume in all other directions are zero.) These give rise to three additional equations.

$$x_2 \geq 200 \quad (6)$$

$$x_3 \geq 300 \quad (9)$$

$$x_5 \geq 1,500 \quad (12)$$

All the given data are contained in these 8 equations. These are the 8 independent equations governing the problem. It is not possible, nor permissible, to create additional independent equations by combining these 8 equations, such as subtracting Eq. (6) from Eq. (1) to form a new Eq. (7). The author obtained Eqs. (7), (8), (10), (11), (13) and (14) in this manner. These and the original 8 equations are lumped together to form a set of 14 simultaneous equations. This is incorrect.

According to linear programming, we convert the inequalities to equations by introducing the "slack variables" x_7, x_8, x_9, x_{10} and x_{11}. The 8 equations (or inequalities) become the following:

$$\begin{aligned}
x_1 + x_2 + x_5 &= 4,140 \\
x_2 + x_3 + x_6 &= 6,240 \\
x_3 + x_4 + x_5 &= 4,680 \\
x_1 + x_4 + x_6 - x_7 &= 6,000 \\
x_1 + x_4 + x_6 + x_8 &= 8,000 \\
x_2 - x_9 &= 200 \\
x_3 - x_{10} &= 300 \\
x_5 - x_{11} &= 1,500
\end{aligned}$$

We note that there are 11 unknowns in these 8 equations. This is typical of linear programming problems. The true traffic volumes can be obtained by solving these 8 (not author's 14) equations, together with the objective function (if it is valid).

(There are several typographical errors in the third line of Table IV, and in Eqs. (7), (8) and (9) in the First Tableau.)

Linear programming is a highly powerful mathematical tool. Properly applied, it will solve many complex and heretofore unsolvable problems. It holds the bright promise to lift the highway traffic analysis from its present state of "my-method-is-as-good-as-yours" and place it on a sound and rational basis. Some pioneering work has already been done by LaVallee,[1] Garrizon, Marble[2] and others. It is hoped that more traffic engineers will direct their attention to this new mathematical tool.

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PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Department of Conditions of Practice are identified by the symbols (PP). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper number are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1859 is identified as 1859 (HY7) which indicates that the paper is contained in the seventh issue of the Journal of the Hydraulics Division during 1958.

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JANUARY: 1892(AT1), 1893(AT1), 1894(EM1), 1895(EM1), 1896(EM1), 1897(EM1), 1898(EM1), 1899(HW1), 1900(HW1), 1901(HY1), 1902(HY1), 1903(HY1), 1904(HY1), 1905(PL1), 1906(PL1), 1907(PL1), 1908(PL1), 1909(ST1), 1910(ST1), 1911(ST1), 1912(ST1), 1913(ST1), 1914(ST1), 1915(ST1), 1916(AT1)[c], 1917(EM1)[c], 1918(HW1)[c], 1919(HY1)[c], 1920(PL1)[c], 1921(SA1)[c], 1922(ST1)[c], 1923(EM1), 1924(HW1), 1925(HW1), 1926(PL1), 1927(HW), 1928(HW1), 1929(SA1), 1930(SA1), 1931(SA1), 1932(SA1).

FEBRUARY: 1933(HY2), 1934(HY2), 1935(HY2), 1936(SM1), 1937(SM1), 1938(ST2), 1939(ST2), 1940(ST2), 1941(ST2), 1942(ST2), 1943(ST2), 1944(ST2), 1945(HY2), 1946(PO1), 1947(PO1), 1948(PO1), 1949(PO1), 1950(HY2)[c], 1951(SM1)[c], 1952(ST2)[c], 1953(PO1)[c], 1954(CO1), 1955(CO1),1956(CO1),1957(CO1), 1958(CO1), 1959(CO1).

MARCH: 1960(HY3), 1961(HY3), 1962(HY3), 1963(IR1), 1964(IR1), 1965(IR1), 1966(IR1), 1967(SA2), 1968(SA2), 1969(ST3), 1970(ST3), 1971(ST3), 1972(ST3), 1973(ST3), 1974(ST3), 1975(ST3), 1976(WW1), 1977(WW1), 1978(WW1), 1979(WW1), 1980(WW1), 1981(WW1), 1982(WW1), 1983(WW1), 1984(SA2), 1985(SA2)[c], 1986(IR1)[c], 1987(WW1)[c], 1988(ST3)[c], 1989(HY3)[c].

APRIL: 1990(EM2), 1991(EM2), 1992(EM2), 1993(HW2), 1994(HY4), 1995(HY4), 1996(HY4), 1997(HY4), 1998(SM2), 1999(SM2), 2000(SM2), 2001(SM2), 2002(ST4), 2003(ST4), 2004(ST4), 2005(ST4), 2006(PO2), 2007(HW2)[c], 2008(EM2)[c], 2009(ST4)[c], 2010(SM2)[c], 2011(SM2)[c], 2012(HY4)[c], 2013(PO2)[c].

MAY: 2014(AT2), 2015(AT2), 2016(AT2), 2017(HY5), 2018(HY5), 2019(HY5), 2020(HY5), 2021(HY5), 2022(HY5), 2023(PL2), 2024(PL2), 2025(PL2), 2026(PP1), 2027(PP1), 2028(PP1), 2029(PP1), 2030(SA3), 2031(SA3), 2032(SA3), 2033(SA3), 2034(ST5), 2035(ST5), 2036(ST5), 2037(ST5), 2038(PL2), 2039(PL2), 2040(AT2)[c], 2041(PL2)[c], 2042(PP1)[c], 2043(ST5)[c], 2044(SA3)[c], 2045(HY5)[c], 2046(PP1), 2047(PP1).

JUNE: 2048(CP1), 2049(CP1), 2050(CP1), 2051(CP1), 2052(CP1), 2053(CP1), 2054(CP1), 2055(CP1), 2056(HY6), 2057(HY6), 2058(HY6), 2059(IR2), 2060(IR2), 2061(PO3), 2062(SM3), 2063(SM3), 2064(SM3), 2065(ST6), 2066(WW2), 2067(WW2), 2068(WW2), 2069(WW2), 2070(WW2), 2071(WW2), 2072(CP1)[c], 2073(IR2)[c], 2074(PO3)[c], 2075(ST6)[c], 2076(HY6)[c], 2077(SM3)[c], 2078(WW2)[c].

JULY: 2079(HY7), 2080(HY7), 2081(HY7), 2082(HY7), 2083(HY7), 2084(HY7), 2085(HY7), 2086(SA4), 2087(SA4), 2088(SA4), 2089(SA4), 2090(SA4), 2091(EM3), 2092(EM3), 2093(EM3), 2094(EM3), 2095(EM3), 2096(EM3), 2097(HY7)[c], 2098(SA4)[c], 2099(EM3)[c], 2100(AT3), 2101(AT3), 2102(AT3), 2103(AT3), 2104(AT3), 2105(AT3), 2106(AT3), 2107(AT3), 2108(AT3), 2109(AT3), 2110(AT3), 2111(AT3), 2112(AT3), 2113(AT3), 2114(AT3), 2115(AT3), 2116(AT3), 2117(AT3), 2118(AT3), 2119(AT3), 2120(AT3), 2121(AT3), 2122(AT3), 2123(AT3), 2124(AT3), 2125(AT3).

AUGUST: 2126(HY8), 2127(HY8), 2128(HY8), 2129(HY8), 2130(PO4), 2131(PO4), 2132(PO4), 2133(PO4), 2134(SM4), 2135(SM4), 2136(SM4), 2137(SM4), 2138(HY8)[c], 2139(PO4)[c] 2140(SM4)[c].

SEPTEMBER: 2141(CO2), 2142(CO2), 2143(CO2), 2144(HW3), 2145(HW3), 2146(HW3), 2147(HY9), 2148(HY9), 2149(HY9), 2150(HY9), 2151(IR3), 2152(ST7)[c], 2153(IR3), 2154(IR3), 2155(IR3), 2156(IR3), 2157(IR3), 2158(IR3), 2159(IR3), 2160(IR3), 2161(SA5), 2162(SA5), 2163(ST7), 2164(ST7), 2165(SU1), 2166(SU1), 2167(WW3), 2168(WW3), 2169(WW3), 2170(WW3), 2171(WW3), 2172(WW3), 2173(WW3), 2174(WW3), 2175(WW3), 2176(WW3), 2177(WW3), 2178(CO2)[c], 2179(IR3)[c], 2180(HW3)[c], 2181(SA5)[c], 2182(HY9)[c], 2183(SU1)[c], 2184(WW3)[c], 2185(PP2)[c], 2186(ST7)[c], 2187(PP2), 2188(PP2).

c. Discussion of several papers, grouped by divisions.

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HW 3

SEPTEMBER 1959 — 32 NO. HW 3
VOLUME 85 PART 2

Your attention is invited

NEWS OF THE HIGHWAY DIVISION OF ASCE

JOURNAL OF THE HIGHWAY DIVISION
PROCEEDINGS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS

DIVISION ACTIVITIES
HIGHWAY DIVISION
Proceedings of the American Society of Civil Engineers

NEWS

September, 1959

THE FEDERAL HIGHWAY PROGRAM
(An Editorial)

The Federal Highway Program anticipates a financial crisis. The Highway trust fund from which all Federal aid for highways stems, anticipates a deficit in the fiscal years 1960 and 1961.

The status of Interstate Highway Construction programs this Spring indicated that about 5000 miles of the interstate system have been completed, almost all of which has been opened to traffic. This represents about 12 percent of the total system. Construction was underway on 3900 more miles and survey and plans on a considerable number of additional miles was underway. Last February 26, Federal Highway Administrator B. D. Tallamey reported 28 percent of the interstate system either completed or underway, representing about 11,500 miles.

During the same period, highway construction on the primary and secondary system (not including the above figures for the interstate system) is 3% ahead of schedule. There has been advertised and obligated a total of 55,290 miles costing about 4.1 billion dollars. In an effort to stave off a recession, the Congress last year authorized $400 million for Federal aid highways other than those on the interstate system, so-called "D" funds. The entire 400 million has been spent or obligated, and the outlook at present indicates all the work will be completed by December 1, 1959.

In the Federal Aid Highway Act of 1956, Congress created a Highway Trust Fund. Money for the fund comes from earmarked taxes on highway users. This Trust Fund is not included in the Federal budget as a part of the total Government budgetary expense.

It was originally estimated that the taxes on highway users would produce 38.5 billion dollars over a 16 year period, 24.8 billion of which was for the interstate system. This amount would provide 90 percent of funds needed for that system, the other 10 percent to come from the States, and a 4 billion

Note: No. 1959-32 is part of the copyrighted Journal of the Highways Division, Proceedings of the American Society of Civil Engineers, Vol. 85, HW 3, September, 1959.
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fund for other Federal aid systems from which the States would share equally with the Federal Government.

The financing provisions of the 1956 Act anticipated a shortage in the trust fund for fiscal year 1962, and provisions to borrow from the Treasury were made. This borrowing, which would make up the anticipated shortages as they occurred, was to be repaid from the trust fund with interest. However, a late amendment to the bill restricted the annual apportionment to the States to the amount actually on hand at the time the bills became due, in a sense nullifying the authorizations made for the system. The effect was a sharp reduction in the amount apportioned to the States.

Then Congress further strained the Highway Trust Fund by setting aside the plan for 1959 and 1960 to permit full apportionment to the States in an amount totalling 1.2 billion. It is estimated the trust fund will be short 4.4 billion of the amount authorized by Congress for the interstate system for fiscal 1961 and 1962.

This all adds up to a balance in the trust fund of 700 million on July 1, 1959, and a deficit of 100 million by July 1, 1960. By July 1, 1961, this will increase to 900 million. Under former plans of Federal authorization and allocation of funds, it would require 50 years to complete the interstate system of 41,000 miles. The Congressional 1958 plan estimated the shortest possible time for completion would be 16 years. Federal tax revenue under the old plan was insufficient to pay the cost of the interstate project and the highway user was tapped for $14,814 million in new taxes. The general fund was available for the balance of $25,604 million from old tax sources.

The 1958 revised estimates revealed the need for a billion more to complete the interstate system. This was due to traffic forecasts for 1975 which increased the need for expensive grade separations and provisions for public and private utility changes. Provisions have not been made for these increased costs.

Many state highway officials and other experts in the highway industry are hoping that long range financial plans for the Federal aid program can be deferred until the Section 210 study (due January 2, 1961) has been completed, and until information is made available from the current road tests now in progress by A.A.S.H.O. in Illinois. These two studies should give Congress further information on which to base a more equitable distribution of the tax burden.

In the meantime, an interim financing plan should be developed which will assure the continuation of the Federal Highway Program. This will involve a method to bring roughly 4.4 billion additional revenue into the trust fund between the fiscal years 1962 and 1964. The situation facing the Highway Trust Fund clearly indicates its future as a source of revenue for highway expenditure is dependent on action by this Congress. The battle for the 41,000-mile system has only started; well informed leadership at both Federal and Local levels is needed now for the development of a sound highway program.

William A. McWilliams
Member, Executive Committee;
City Manager, Rehoboth Beach,
Delaware

* * *

PURPOSE OF THE HIGHWAY DIVISION

(a) The advancement of the science of civil engineering as related to the administration, economics, planning, design, construction, operation, and maintenance of civil and military highways; and

(b) The professional improvement of civil engineers interested in highway and related work.

The division works toward these objectives by:

(1) presentation and discussion of papers at Society meetings and in Society publications;

(2) appointment of committees to study and report upon particular subjects;

(3) promoting highway engineering education; and

(4) cooperation with other organizations engaged in similar or related activities.

COMMITTEE NEWS

Committee on Research

Commissioner Ellis L. Armstrong, of the United States Bureau of Public Roads, has joined the membership of this committee, serving for a three-year term ending in October 1961.

New Committee on Highway Drainage Structures

The organization of this new committee has been completed. The membership is as follows:

Frederick W. Thorstenson (Chairman)
Hydraulic Engineer
State Highway Department
New Highway Building
St. Paul 1, Minnesota

John G. Hendrickson, Jr.
American Concrete Pipe Association
228 N. La Salle Street
Chicago, Illinois

Robert A. Norton
Hydraulics Engineer
State Highway Department
P. O. Box 2188
Hartford 15, Connecticut

Winifred T. Robertson
Principal Bridge Engineer
Department of Highways
Transportation Building
Olympia, Washington

Edwin R. Rowe
Associate Highway Engineer
Division of Highways
150 Oak Street
San Francisco, California

New Committee on Pipeline Crossings

The membership of this new committee is as follows:

R. Robinson Rowe (Chairman)
2701 Third Avenue
Sacramento 18, California

Talbot S. Huff
Engineer, Road Design
State Highway Department
State Highway Building
Austin 14, Texas

Hubert H. Brown
Engineer of Materials
State Highway Department
206 S. 17th Avenue
Phoenix, Arizona

Douglas B. Fugate
Chief Engineer
Department of Highways
1221 East Broad Street
Richmond 19, Virginia

Edward F. Kauffman
Assistant Design Engineer
Department of Highways
Capitol Office Building
Oklahoma City, Oklahoma

Sylvester E. Ridge
Assistant Chief, Division of Development
United States Bureau of Public Roads
1717 H. Street, N. W.
Washington 25, D. C.

LAND USE AND TRANSPORTATION PLANNING

The newest techniques in the field of land use and transportation planning are explained in the May issue of the Journal of the American Institute of Planners. Experts in city and traffic planning describe certain planning situations in which they have used the latest techniques effectively.

The authors outline their conclusions regarding the influence of land use on transportation patterns and the reciprocal effect of transportation facilities on land use and traffic patterns. There are also discussions of revolutionary methods of forecasting traffic and land use patterns. All the procedures as presented in the Journal have been tested on a practical basis.

The new techniques are based on the theory that cities display similar characteristics, and that there is a striking regularity in urban growth and form. Researchers in city and traffic planning believe that personal travel habits are predictable, and that mathematical formulas can be developed to express travel behavior and to express land use patterns.

On the basis of extensive field tests, some completed and some in progress the new traffic forecasting techniques hold the promise of saving United States cities millions of dollars in road and street construction costs and of giving motorists vastly improved traffic service.

It is said that the new traffic forecasting technique already has produced substantial savings to several cities. In communities where the techniques were tried out, it was possible to relocate a number of proposed highways through sections where right-of-way costs were lower and where better ultimate traffic service would be provided.

Extensive research by the Bureau of Public Roads, state highway departments, city planning agencies and the Automotive Safety Foundation preceded development and perfection of the new traffic forecasting techniques.

URBAN PLANNING AND TRAFFIC ENGINEERING AT YALE

A combined urban planning and traffic engineering program has been announced by Yale University. The program, which will lead to both a Master of City Planning degree and a Certificate in Highway Traffic, will extend over a period of two academic years. The first class will be enrolled in September 1959.

The integration of urban planning and traffic engineering disciplines is achieved by combining portions of the regular courses offered by the Bureau of Highway Traffic and by the graduate program in city planning.

The traffic engineering portion of the curricula is based on engineering disciplines. The city planning part is based on the concept that planning is the rational integration of the art and science of community development.

TRAFFIC & TRANSPORTATION STUDIES AT NORTHWESTERN UNIVERSITY

The Traffic Institue of Northwestern University will be joined administratively with the Transportation Center at Northwestern. Heretofore the two organizations bave been separate administrative units within the University in Evanston, Illinois.

The Traffic Institute will now become a division of the Transportation Center, retaining its own director and maintaining its present program.

The Transportation Center offers a broad program of graduate and undergraduate training aimed at solving major problems in the highway, rail, air, pipeline, and water divisions of the nation's transportation industry. Research and consultative services also are part of the Center's program.

The Traffic Institute functions in the street and highway traffic field. Originally a police traffic training school, it has expanded its activities to include courses for virtually all types of traffic safety, personnel, research and development work, publications, and field service assistance to local and state governments.

PATH OF AN ASCE MEETING MANUSCRIPT

1. The Technical Publications Handbook contains essential information for the guidance of authors, editors, and Division reviewers, the basic requirements being abstracted and printed on the inside front cover. These basic requirements are standing matter which now appears on the inside front cover of every Division Journal.

2. Some meeting papers are prepared with publication in mind, the oral presentation being abstracted from the longer draft. Such papers should be transmitted directly to the Manager of Technical Publications for review by the appropriate Technical Division. The path of such a manuscript is fully described in the Technical Publications Handbook.

3. An author sometimes provides a supply of mimeographed copies of his paper for distribution among those who attend his meeting presentation. Such authors will assist greatly if any copies remaining unused after the meeting presentation are brought to the Publications Center for free distribution during the remainder of the Convention.

4. The Society's Public Relations Department is interested in examining the content of every paper, speech or otherwise, for possible release to local and national magazines and newspapers.

5. The editors of CIVIL ENGINEERING, working in cooperation with the Technical Divisions, are also interested in the possibility of publishing papers with a construction emphasis and those having broad professional interest.

6. Restrictions of style, form and content applying to PROCEEDINGS PAPERS, do not necessarily apply to CIVIL ENGINEERING papers. A good CIVIL ENGINEERING paper can often be made of an oral meeting paper, provided the Technical Division, the author and the CIVIL ENGINEERING editors are in accord as to the appropriateness of the subject matter. The

editors of CIVIL ENGINEERING go to considerable lengths to adapt the authors' ideas to the space limitations of that magazine.

7. Incidentally, it would be a service to the Society if every member could consider himself a self-appointed reporter for material of either technical or news interest to the Society's publications. Only in this way will it be possible for the Society's publications to meet the many needs of a Society publication.

8. Reporters from other publishing organizations are welcome to attend all sessions and are free to report from their own notes of the spoken address, provided only that information declared "off the record" by the author be expunged, and that suitable credit is given for quoted matter.

PERTINENT PUBLICATIONS

A Career For You in Highway Engineering - by a Joint Committee of A.A.S.H.O. and ASCE Highway Division. Published with cooperation of State Highway Departments and Automotive Safety Foundation, 200 Ring Building, Washington 6, D. C. 1958 24 pp. $0.30.

This booklet was published late last year to encourage high school students to make highway engineering their profession.

The fourth printing of the booklet is now on the press to meet orders from more than a third of the State Highway Departments and from others concerned about a national shortage of highway engineers in the years ahead.

The booklet was sponsored by the Joint Committee of the American Association of State Highway Officials and the Highway Division of the American Society of Civil Engineers. The Automotive Safety Foundation is serving as the agency for distribution of the booklet on a cost basis.

It is suggested that the booklet be distributed to high school guidance counselors and teachers, and college professors.

Costs are: Up to 5,000 copies, thirty cents per copy; for 5,000 or more write for quotations; special imprints of messages on the outside back cover will vary in accordance with the length (generally not over $15.00).

Address orders to: Automotive Safety Foundation, 200 Ring Building, Washington 6, D. C.

Studies in Highway Administration - Bulletin 200, Highway Research Board, National Research Council, 2101 Constitution Avenue, Washington 25, D. C. 1959 50 pp. $1.00

This bulletin contains seven papers on highway administration at the state, county, and local levels, as presented at the 37th Annual Meeting of the Highway Research Board. The following papers are included:

"Principles of Delegation of Authority and Responsibility in a Highway Department," by K. L. Bergstralh.

"Decentralization in Highway Administration," by W. L. Haas.

"Wisconsin's Education and Training for Highway Construction Engineering Aides or Technicians," by C. L. Greiber.

"A Program for Development and Research in Local Rural Highway Administration," by J. E. Stoner.

"A Study of Human Relationships in County Road Administration," by K. F. Jones.

"Effect of the New Interstate System on Intergovernamental Relations in Kansas," by C. J. Hein.

"Considerations and Methods for Developing Metropolitan Area Transportation Studies," by T. J. Owens.

Australian Road Practice, by H. M. Sherrard, Cambridge University Press, 32 East 57th Street, New York 22, New York. 1959 407 pp. $19.50

Subtitled "An Introduction to Highway Engineering," this book is a new publication by the Commissioner for Main Roads of the state of New South Wales.

Beginning with a thorough examination of the nature of soil and drainage, the author then deals with such subjects as pavement design, materials, construction plant and methods, and the organization of construction. Methods and organization of road maintenance are treated fully, and attention is given to the principles and practice of road design. The book concludes with a consideration of the problems of road administration and finance.

The Federal Role in Highway Safety - House Document No. 93, 86th Congress, 1st Session. Superintendent of Documents, Government Printing Office, Washington 25, D. C. 1959. 232 pp. $0.60.

This study was undertaken, and the report prepared, by the Bureau of Public Roads, as required by Section 117 of the Federal - Aid Highway Act of 1956.

In its opening statement the report summarizes findings of the study and recommends actions that can be taken by the Federal Government to promote highway safety.

Chapter III reviews the highway transportation system - the driver, the vehicle, the highway - as related to safety. Chapter IV evaluates current highway safety activities, and Chapter V discusses the nature of an adequate safety program.

Improving Highway Transportation Through Official Coordination - Automotive Safety Foundation, 200 Ring Building, Washington 6, D. C. January, 1959, 19 pp. Free.

This pamphlet reports a number of speeches presented at a meeting of the Traffic and Enforcement Committee of the American Association of Motor Vehicle Administrators in September 1958. Included are addresses by B. R. Caldwell, Joseph E. Havenner, Hoyt Ray, and Edward Scheidt.

Travel Characteristics in Urban Areas - Bulletin 203, Highway Research Board, National Research Council, 2101 Constitution Avenue, Washington, D. C. 1958. 130 pp. $2.60

This bulletin contains seven papers given in a session sponsored by the Committee on Origin and Destination Surveys at the 37th Annual Meeting of the Highway Research Board, as Follows:

"Travel Characteristics of Two San Diego Subdivision Developments," by Edward M. Hall.

"Factors Affecting Trip Generation of Residential Land Use Areas," by G. B. Sharpe, W. G. Hansen and L. B. Hamner.

"Forecasting Peak Hours of Travel," by Alan M. Voorhees.

"Transportation Usage Study," by William J. Mortimer.

"Evaluating Trip Forecasting Methods with an Electronic Computer," by G. E. Brokke and W. L. Mertz.

"Center City Goods Movement: An Aspect of Congestion," by Edgar M. Horwood.

"Travel Patterns in 50 Cities," by F. B. Curran and J. T. Stegmaier.

Planning for Urban Transportation - 2nd Annual Spring Conference of the Organization of Cornell Planners. College of Architecture, Franklin Hall, Cornell University, Ithaca, New York. 85 pp. limited supply. $2.00.

This is a booklet containing discussions on "Transportation as a Builder of Cities," "Trends in Urban Transportation," "Framework for Planning - Search for a Policy," "Land Use Planning in an Age of Changing Transportation Patterns," and "Metropolitan Transportation."

Highway Laws - 1958 - Bulletin 205, National Research Council, 2101 Constitution Avenue, Washington, D. C. 34 pp. $0.80.

This is a report of 1957 activities of the Committee on Highway Laws, as presented at the 37th Annual Meeting of the Highway Research Board, together with three papers sponsored by the Committee ot the same meeting, as follows:

"Control of Access and Police Power," by Stanley Nissel.

"A Program of Highway Research at the University of Wisconsin," by J. H. Benscher, Donald Heaney, Ray Vlasin, and F. M. Covey, Jr.

"The Law and Highway Modernization," by Clifton W. Enfield.

MEETING CALENDAR

ASCE MEETINGS - 1959

October 19-23 — Washington Convention

Contact: Carl E. Fritts
Automotive Safety Foundation
200 Ring Building
Washington 6, D. C.

1960

March 7-11 — New Orleans Convention

Contact: Louis Duclos
Assistant Bridge Design Engineer
State Department of Highways
Baton Rouge, Louisiana

June 19-23 — Reno Convention

Contact: George Langsner
Engineer of Design
Division of Highways
P. O. Box 1499
Sacramento 7, California

October 10-14 Boston Convention

Contact: E. F. Copell
Chief Engineer
New England Division
De Leuw Cather & Co.
361 Boyleston Street,
Brookline 46, Massachusetts

Non-ASCE Meetings - 1959

September 14-17 Institute of Traffic Engineers
29th Annual Meeting
Hotel Commodore, New York City

Contact: ITE
2029 K Street, N. W.
Washington 6, D. C.

October 11-16 American Association of
State Highway Officials
Annual Meeting
Hotel Statler-Hilton
Boston, Massachusetts

Contact: AASHO
917 National Press Building
Washington 4, D. C.

Early Transactions
Volumes Obtainable

The feasibility of reproducing the first ten volumes of ASCE TRANSACTIONS (1872-1881) has been studied. It has been decided that these historic volumes could be reproduced at a cost that would permit a top price of $150 for the ten-volume set. If more than 100 engineers, or libraries, indicate an interest in obtaining such a set, the project will be undertaken. If the endeavor is successful, other rare volumes of TRANSACTIONS will be reprinted.

Engineers interested in obtaining the ten-volume set should write to the Executive Secretary of ASCE, 33 West 39th Street, New York 18, N. Y. Deadline date for December 1959 Newsletter: October 15, 1959.

Send contributions to:

Edmund J. Cantilli
Room 1539
The Port of New York Authority
111 Eighth Avenue
New York 11, New York

Aluminum Construction Manual

The Aluminum Construction Manual, just off the press, provides in a single volume data essential to designers and others concerned with stressed aluminum structures. Published by the Aluminum Association, an industry-wide organization, the book presents for the first time computations of allowable loads for beams and columns of aluminum alloy 6061-T6, one of the most widely used aluminum structural alloys.

Fundamentally a reference work, the first part relates to available aluminum structural shapes, giving their dimensions, weights, and properties. Included also are the standard tolerances and miscellaneous data necessary for designing and estimating. This is followed by detailing practice and data on riveted and bolted connections.

A section covers the hitherto unavailable material for beams and columns produced in alloy 6061-T6. The data for various types of laterally supported beams and concentric loads on columns were computed by the Polytechnic Institute of Brooklyn. The work was supervised by R. B. B. Moorman, head of the Institute's Civil Engineering Department.

Data are given on nine alloys that fulfill most structural needs. Found here are the specifications for structures of two commonly used alloys (6061-T6 and 2014-T6) as issued by ASCE.

Making dependable data needed for design readily available is expected to increase use of the light-weight metal. The book is available at cost of printing—$3.00 per copy—from the Aluminum Association, 420 Lexington Ave., New York 17, N. Y.